SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, NAOTO JIKUTANI, a citizen of Japan residing at Miyagi, Japan, SHUNICHI SATO, a citizen of Japan residing at Miyagi, Japan, TAKASHI TAKAHASHI, a citizen of Japan residing at Miyagi, Japan, AKIHIRO ITOH, a citizen of Japan residing at Miyagi, Japan, TAKURO SEKIYA, a citizen of Japan residing at Kanagawa, Japan, AKIRA SAKURAI, a citizen of Japan residing at Kanagawa, Japan, MASAYOSHI KATOH, a citizen of Japan residing at Kanagawa, Japan, TERUYUKI FURUTA, a citizen of Japan residing at Kanagawa, Japan, KAZUYA MIYAGAKI, a citizen of Japan residing at Kanagawa, Japan, KEN KANAI, a citizen of Japan residing at Tokyo, Japan, ATSUYUKI WATADA, a citizen of Japan residing at Shizuoka, Japan, KOEI SUZUKI, a citizen of Japan residing at Miyagi, Japan, SATORU SUGAWARA, a citizen of Japan residing at Miyagi, Japan, SHINJI SATOH, a citizen of Japan residing at Kanagawa, Japan and SHUUICHI HIKICHI, a citizen of Japan residing at Miyagi, Japan have invented certain new and useful improvements in

SURFACE-EMISSION LASER DIODE OPERABLE IN THE
WAVELENGTH BAND OF 1.1 - 1.7μm AND OPTICAL
TELECOMMUNICATION SYSTEM USING SUCH A LASER DIODE

of which the following is a specification:-

BACKGROUND OF THE INVENTION

This invention generally relates to laser diodes and further to the art of optical telecommunication that uses a laser diode. Especially this invention is related to a so-called surface-emission laser diode that emits a laser beam in a generally vertical direction to a substrate surface. Also, the present invention is related to an optical transmission/reception system and optical-fiber telecommunication system that uses such a surface-emission laser diode. Further, the present invention relates to a semiconductor distributed Bragg reflector and also a surface-emission laser diode and further a surface-emission laser array. Further, the present invention relates to a surface-emission laser module, an optical interconnection system and an optical telecommunication system.

A surface-emission laser diode is a laser diode that emits a laser beam in a generally vertical direction from a surface of a substrate. By using surface-emission laser diodes, two-dimensional array integration of laser diode is achieved easily. Further, the laser diode has an advantageous feature of relatively narrow divergent angle of the output optical beam (about 10 degrees), which is

particularly suitable for coupling with optical
fibers. Furthermore, inspection of the laser diode
device is made easily in a surface-emission laser
diode.

5   Thus, surface-emission laser diodes are
suited to construct an optical transmission module
(optical interconnection apparatus) of parallel-
transmission type, and research and development are
conducted prosperously. The immediate application of
10   the optical interconnection apparatus would be the
parallel connection between computers or circuit
boards in a computer, including short-range optical-
fiber telecommunication. In future, application to a
large-scale computer network and trunk line system of
15   long-range, large-capacity telecommunication is
expected.

        Generally, a surface-emission laser diode
includes an active layer of a group III-V
semiconductor material such as GaAs or GaInAs, and an
20   optical resonator is formed by disposing an upper
semiconductor Bragg reflector and a lower
semiconductor Bragg reflector arranged respectively
above and below the active layer.

        In such a construction, the length of the
25   optical resonator is remarkably short as compared

with the case of an edge-emission laser diode.
Therefore, it is necessary to increase the
reflectance of the reflector to a high value (99% or
more) for facilitating laser oscillation. Because of
5 this, it is practiced to use a semiconductor Bragg
reflector in a surface-emission laser diode as a
reflector, wherein a semiconductor Bragg reflector is
formed of an alternate and repetitive stacking of a
high-refractive index material such as GaAs and a low
10 refractive index material such as GaAs with a period
of 1/4 wavelength.

However, in the conventional semiconductor
Bragg reflector that has the structure mentioned
above, there arises a spike structure in the energy
15 band as a result of band discontinuity at the hetero
interface, at which the materials of different
bandgaps are jointed, and the spike structure thus
formed tends to function as a barrier against
carriers. Thereby, there arises a problem in that the
20 semiconductor multilayer part increases the
resistance of the laser diode. Because of this,
conventional surface-emission laser diodes
constructed on a GaAs substrate have suffered from
the problem of comparatively high operating voltage
25 of about 2.5 volts or more. Because of this, it has

been difficult to use the surface-emission laser
diode with a CMOS driver integrated circuit, which
produces a laser driving voltage of 2 volts at best.
The itemization of this operating voltage of 2.5

5   volts is: 1.5V for the diode part; and 1V for the
device resistance. In order to reduce the operational
voltage below 2 V, it is necessary to reduce the
device resistance by one-half, while it is extremely
difficult to meet for this requirement at the present

10   stage of technology.

In the case of a laser diode of long-
wavelength band for use in optical telecommunication,
such as the laser diode of 1.3μm band or 1.55μm, a
low voltage operation is expected in view of the fact

15   that only a voltage of 1 volt or less is applied to
the diode part of the laser diode. Unfortunately, the
desired low voltage operation is not materialized in
such a long wavelength laser diode. In conventional
long-wavelength laser diode, InP is used for the

20   substrate and InGaAsP is used for the active layer.
In such a system, the lattice constant of InP
constituting the substrate is large, and it is
difficult to achieve a large refractive-index
difference in the reflector when a material that

25   achieves lattice matching with the InP substrate is

used for the reflector. Consequently, it has been necessary to stack 40 or more pairs in the reflector for realizing sufficient reflectance. In such a construction, however, the resistance of the

5   reflector increases again as a result of increased stacking number of the reflector. Thus, it has been difficult to drive the laser diode driver by a CMOS integrated circuit.

In a surface-emission laser diode formed on

10 an InP substrate, there is another problem of change of laser characteristic caused by the temperature. Because of this, it has been necessary to add an apparatus for stabilizing the temperature in the laser diode constructed on such an InP substrate.

15 However, the use of such a temperature regulator is difficult in the apparatus for home use, which is subjected to a severe demand of cost reduction. Because of these problems of increased number of stacking in the reflector and the poor temperature

20 characteristics, practical long-wavelength surface-emission laser diode has not yet commercialized.

In order to deal with the foregoing problems, there is a proposal to construct a surface-emission laser diode on a GaAs substrate by using an

25 AlInP layer, which achieves a lattice matching with

the GaAs substrate, in at least one of the upper and lower semiconductor Bragg reflectors as the low refractive index layer, and further by using a GaInNAs layer in at least one of the upper and lower

5   semiconductor Bragg reflectors, as disclosed in Japanese Laid-Open Patent Application 9-237942, such that a large refractive index difference is realized in the reflector and the number of stacking therein is reduced while maintaining high reflectance.

10   In the foregoing conventional art, the bandgap of the active layer is reduced by 1.4eV by using GaInNAs, in which N is introduced into the III-group V semiconductor material system of GaInAs. As a result, the laser diode can produce an optical beam

15   with a wavelength longer than 0.85μm. In the aforementioned prior art, it should be noted that the material system of GaInNAs can achieve a lattice matching with the GaAs substrate. Further, the prior art describes the semiconductor layer of GaInNAs can

20   be a promising material for the long-wavelength surface-emission laser diode operable in the 1.3 micron band and 1.55 micron band.

In spite of such a description in the prior art with regard to the possibility of surface

25   emission laser diode operable in the wavelength band

longer than 0.85μm, there has no such a laser diode

actually materialized. The present situation would be

something like that the theoretical construction is

already established but the actual construction for

5   materializing the laser diode is not discovered yet.

In one example, there is a laser diode that

uses a semiconductor Bragg reflector formed by

stacking high-refractive index material layers of

GaAs and low refractive index material layers of AlAs

10   alternately as noted above with the periods of 1/4

wavelength. However, the laser diode structure thus

formed does not provide optical emission at all, or

operates but only with low power, indicating that the

efficiency of optical emission is extremely small.

15   Similarly, there is a laser diode disclosed

in the Japanese Laid Open Patent Application 9-237942

in which an AlInP layer is used for the low

refractive index layer of the semiconductor Bragg

reflector. In this case, too, the luminous efficacy

20   of the laser diode is far from the level of practical

use.

The reason of this unsatisfactory result is

attributed to the chemical activity of the material

including Al. More specifically, it is thought that

25   the use of a material containing Al easily invites

formation of crystal defects originating from Al.
Thus, there have been proposals, as in the Japanese
Laid-Open Patent Application 8-340146 and Japanese
Laid-Open Patent Application 7-307525, to construct

5 the semiconductor Bragg reflector with materials free
from Al such as GaInNP and GaAs. However, the
material system of GaInNP and GaAs can provide a
refractive-index difference of about half as compared
with the material system of AlAs and GaAs. Thus, the

10 stacking number in the reflector has to be increased,
and the object of reducing the resistance of the
surface-emission laser diode is not attained.

Thus, at present, the surface-emission
laser diode operable at the long-wavelength of 1.1 -

15 1.7μm does not exist, and because of this, it is not
possible to construct a computer network or optical-
fiber telecommunication system that uses such a laser
diode.

As explained before, in a conventional

20 surface-emission laser diode, it was also not
possible to use a CMOS circuit for the laser diode
driver, and it has been necessary to use an expensive
special driver circuit. On the other hand, if a mass-
produced CMOS driver integrated circuit could be used,

25 the cost of the optical telecommunication system that

uses such a surface-emission laser diode would be reduced significantly.

Furthermore the use of a CMOS circuit can reduce the power supply voltage of the driver
5 integrated circuit as well from 5V to 3.3V. With this, it is possible to reduce the power consumption of the system to about one-half, and a very large effect of electric power saving is obtained.

As noted before, there is a widespread
10 expectation of optical-fiber telecommunication in relation to computer networks, and the like. Especially, there is a need of realizing a low cost system in order that the public accepts such an optical telecommunication system. Unfortunately, the
15 surface-emission laser diode that can be used for this purpose and can be used with a low-cost CMOS driver integrated circuit, and oscillates at the long-wavelength band of 1.1 - 1.7μm does not exist. Hence, the telecommunication system that uses such a
20 surface emission laser diode does not exist.

Meanwhile, in the abovementioned semiconductor Bragg reflector, in which semiconductor layers of different bandgaps are grown alternately, there arises the problem of spike formation in the
25 band structure thereof at the hetero interface as a

result of the band discontinuity. When such a spike
structure is formed, the spike structure functions as
a barrier with regard to the carriers. Thus, there
arises a problem in that the electric resistance
5   becomes very high in the semiconductor multilayer
part of the surface-emission laser diode. This effect
also contributes to the large drive voltage of 2.5 V
for the surface-emission laser diode constructed on a
GaAs substrate. As noted previously, it has been
10   difficult to drive a laser diode having such a large
driving voltage by the driver integrated circuit
formed of a CMOS circuit (driving voltage is below 2
volts).

As noted previously, the itemization of
15   this operating voltage of 2.5 volts is: 1.5V for the
diode part; and 1V for the device resistance, and it
is necessary to reduce the device resistance by one-
half in order to drive the laser diode with a drive
voltage below 2 volts. However, this is a very
20   difficult subject.

Recently, the optical systems are used also
for peripheral transmission/reception systems, and
there is a widespread expectation about the computer
networks using the optical-fiber telecommunication
25   technology including such a peripheral

transmission/reception system. Especially, there is a keen interest about a low cost optical system required for spreading of the optical fiber technology to the general public. However, the

5   surface-emission laser diode that can be used for this purpose and can be used with a low-cost CMOS driver integrated circuit, and oscillates at the long-wavelength band of 1.1 - 1.7μm does not exist yet. Hence, the telecommunication system that uses

10   such a surface emission laser diode does not exist at the moment.

In such an optical-fiber telecommunication system that uses the long-wavelength surface-emission laser diode operating at the wavelength band of 1.1 -

15   1.7μm, the photodetection device constructed on a Si substrate cannot be used, as such a photodetection device cannot detect the wavelength of 1.1 - 1.7μm. In such a system, it is necessary to use a photodetection device that has a sensitivity to the

20   wavelength of 1.1 - 1.7μm. However, the photodetection device that has sensitivity to the desired wavelength band of 1.1 - 1.7μm is expensive as compared with the low cost Si photodetection device. Thus, simple replacement of a conventional Si

25   photodetection device with the photodetection device

having the sensitivity to the wavelength of 1.1 - 1.7 μm causes an increase of cost of the whole optical-fiber telecommunication system. Thus, in order to realize an optical telecommunication system that uses

5   the long-wavelength surface-emission laser diode of 1.1 - 1.7μm band, an approach other than replacing the conventional Si photodetection device with an expensive photodetection device is needed.

Furthermore, a GaInNAs active layer having

10   a high strain is used in the long-wavelength surface-emission laser diode, as will be explained below. In such a laser diode, deterioration of device characteristic may be caused as a result of the thermal stress caused by the difference of linear

15   thermal expansion coefficient with regard to the mounting substrate.

Meanwhile, in the optical-fiber telecommunication system that uses a surface-emission laser diode, it is possible to arrange a number of

20   laser diode elements, each formed of a surface-emission laser diode, with high integration density. Thus, the distance between the optical fibers can be reduced as compared with the case in which a conventional edge-emission laser diode is used for

25   the laser diode array. Generally, optical fibers

accommodated in an optical cable is provided with a
marker band or a plastic ring in the form of a
coloring layer or identification code (ID mark), in
order to allow identification of the transmission
5   line. When the distance between the optical fibers is
reduced, the space available for these protection
layers or rings is reduced.

        In the production of an optical module that
accommodates therein an array of surface-emission
10 laser diodes, it should be noted that the produced
optical module would becomes a defective product
unless a necessary quality is secured for a
predetermined number of laser diode elements in the
array. Otherwise, the product loses the value thereof.

15   This issue is related to the yield of the
laser diode production process. In the production of
the module product that uses an array arrangement of
the laser diode elements, there is an acute demand of
establishing the production process in which the
20 modules that function normally are utilized
efficiently and the yield of production of the module
is improved.

        Summarizing above, there is no available
long-wavelength surface-emission laser diode operable
25 at the wavelength band of 1.1 − 1.7 μm and that there

is no available optical transmission/reception system
that uses such a laser diode.

Also, it is known in the art of surface-
emission laser diode to provide a structure in which

5   a current confinement layer (Al_2O_3) in a part of the
p-type semiconductor distributed Bragg reflector
close to the active layer by oxidizing an Al(Ga)As
selective oxidation layer for the purpose of reducing
the threshold current density. It should be noted

10   that the current confinement layer of Al_2O_3 is a good
insulator and the holes constituting the carriers are
injected into a limited region of the active layer as
a result of the action of the current confinement
layer, and it becomes possible to increase the

15   carrier density easily to a threshold carrier density
needed for causing laser oscillation. Thereby, it
becomes possible to suppress the threshold current to
sub milliamperes. Because of the fact that the
refractive index of this selective oxidation layer is

20   smaller than the refractive index of the
semiconductor layer, the selective oxidation layer
functions as an effective optical confinement layer
for confining transverse mode, and it becomes
possible to obtain a fundamental transverse mode

25   oscillation in the case of reducing the confinement

diameter to below about 4μm in the case of the device is designed for the 0.98μm band.

In the device in which the confinement diameter is reduced to about 4μm or less as noted above, on the other hand, there arises a problem of increased electrical resistance because of excessive decrease of the current path area in the current confinement structure. In the device in which the confinement diameter is reduced to the above size or less, for example, it should be noted that the confinement resistance caused as a result of such a current confinement structure constitutes more than the half of the device resistance. As such increase of resistance of the device can become the cause of various problems such as increase of operational voltage, saturation of output power caused by heating, decrease of modulation speed, and the like, it is necessary to reduce the resistance of the confinement structure. This includes not only the reduction of resistance of the current confinement region itself but also the resistance of the peripheral part of the current confinement region.

With regard to the cause of such an increase of resistance as a result of using a current confinement structure, it should be noted that there

is a substantial contribution from the high
resistance of the p-type semiconductor device used in
the p-type semiconductor distributed Bragg reflector.
In a semiconductor material, there appears a very

5 high potential barrier at the hetero interface where
two semiconductor layers of different bandgaps are
contacted, and becomes of this, a p-type
semiconductor distributed Bragg reflector generally
shows a very high resistance as compared with an n-

10 type semiconductor distributed Bragg reflector.

Conventionally, it is known in the art of
surface-emission laser diode of 0.98 μm wavelength to
provide a heterospike buffer layer between the two
layers having different Al contents and forming a p-

15 type distributed Bragg reflector, for reducing the
electric resistance of the distributed Bragg
reflector, such that the heterospike buffer layer has
a composition intermediate of these two semiconductor
layers of different kind. Reference should be made to

20 Photonics Technology Letters, Vol.2, No.4, 1990,
pp.234-236, Photonics Technology Letters, Vol.4,
No.12, 1992, pp.1325-1327.

Thus, in the art of surface-emission laser
diode, decrease of resistance of the device is an

25 important subject matter, and active research and

development are being made especially with regard to
the reduction of resistance of p-type semiconductor
distributed Bragg reflectors. For the desired
reduction of the resistance, the use of the hetero

5   barrier buffer layer noted above is extremely
effective. Further, it is similarly very effective to
increase the doping concentration of the
semiconductor layers constituting the semiconductor
distributed Bragg reflector, especially the

10 semiconductor layers including the heterospike buffer
layer and the layers in the vicinity of the foregoing
heterospike buffer layer.

In the case of using a highly doped p-type
semiconductor, it is true that the electric

15 characteristics such as device resistance are
improved, while there also arise problems such as
conspicuous free carrier absorption caused by holes
or conspicuous intra-valence band absorption. Thereby,
the optical properties of the laser diode are

20 degraded. To improve the electric power
transformation efficiency in a surface-emission laser
diode, it is particularly important to reduce the
absorption of the laser beam by the p-type
semiconductor distributed Bragg reflector, while this

25 requirement of reduction of optical absorption loss

contradicts with the requirement of reduction of electric resistance.

To eliminate this problem, Japanese Laid-Open Patent Application 2001-332812 proposes a
5   surface-emission laser diode having a semiconductor distributed Bragg reflector in which the doping concentration of the semiconductor distributed Bragg reflector is made relatively low for the region located at the side of the active layer with respect
10   to the region away from the active layer such that the bandgap difference between the two different semiconductor layers of different refractive indices and constituting the semiconductor distributed Bragg reflector is reduced.

15   In this conventional art, the doping concentration of the semiconductor distributed Bragg reflector located in the vicinity of the active layer is set lower than the doping concentration of other regions, for minimizing the deterioration of the
20   optical output caused by the influence of optical absorption by the semiconductor distributed Bragg reflector. Further, in order to prevent the increase of electric resistance of the semiconductor Bragg reflector caused as a result of reduced doping
25   concentration, the difference of the bandgap is

reduced for the semiconductor layers constituting the foregoing less doped region of the semiconductor distributed Bragg reflector such that the potential barrier height formed at the heterointerface is

5   reduced. In the surface-emission laser element having such a construction, the saturation point of the optical output is increased while simultaneously reducing the device resistance.

Thus, in Japanese Laid-Open Patent
10   Application 2001-332812, the doping concentration is reduced in the region located in the vicinity of the active layer in the purpose of reducing the optical absorption, and the bandgap difference between the two semiconductor layers of different kinds and
15   constituting the semiconductor distributed Bragg reflector is reduced for preventing the increase of electric resistance.

However, such a construction, while being able to reduce the resistance to some extent by
20   reducing the bandgap difference for the semiconductor layers constituting the heterointerface, has still suffered from the problem that the electric resistance cannot be reduced sufficiently due to the fact that the reduction of doping concentration
25   inevitably increases the adversary effect of the

heterointerface.

Further, the device of Japanese Laid-Open
Patent Application 2001-332812 suffers from the
problem in that the reduction of bandgap difference
5   leads to decrease of reflectivity of the
semiconductor distributed Bragg reflector and
penetration of light into the semiconductor
distributed Bragg reflector is increased. In order to
compensate for this decrease of the reflectivity, it
10 is necessary to increase the number of stacks in the
semiconductor distributed Bragg reflector.

Conventionally, it is known in a surface-
emission laser diode of the $0.98 \mu m$ band, and the
like, to provide a hetero barrier buffer layer
15 between the two layers of different Al contents and
constituting the distributed Bragg reflector in the
form of a compositional graded layer having an Al
content intermediate of the foregoing two layers for
reducing the electrical resistance of the p-type
20 semiconductor distributed Bragg reflector. Reference
should be made to Photonics Technology Letters Vol.2,
No.4, 1990, pp.234-236 and Photonics Technology
Letters Vol.4, No.12, 1992, pp.1325-1327.

On the other hand, an n-type semiconductor
25 distributed Bragg reflector generally has a very low

resistance as compared with a p-type semiconductor distributed Bragg reflector, and no detailed examination have been made so far because it was thought that there would be little influence to the

5   device characteristic (such as device resistance of a surface-emission laser diode).

However, there occurs accumulation or depletion of carriers also in an n-type semiconductor distributed Bragg reflector at the heterointerface

10   formed by two semiconductor layers of different kinds as a result of the influence of band discontinuity between two different semiconductor materials. Because of this, the characteristics of the distributed Bragg reflector differ significantly from

15   those of a bulk semiconductor. Particularly, a depletion layer characterized by decreased carrier density forms electrostatic capacitance component, and become of this, restriction is imposed to electric characteristics and device response

20   characteristics when a device (surface-emission laser diode, and the like) is driven to cause pulse operation or high speed modulation. Furthermore, because of the influence of the heterointerface, there is caused the problem in that non-linearity is

25   caused in the current-voltage characteristic and that

the current-voltage characteristic changes in
response to the difference of the drive condition of
the device.

Thus, it is necessary to conduct detailed
5 examination regarding to the structure and electric
characteristics of an n-type semiconductor
distributed Bragg reflector in order to obtain a
device (surface-emission laser diode, and the like)
having excellent characteristics. Conventionally,
10 such detailed examination was not conducted.

SUMMARY OF THE INVENTION

Accordingly, it is a general object of the
present invention to provide a novel and useful
15 surface-emission laser diode operable in a long
wavelength band and an optical transmission/reception
system or optical telecommunication system that uses
such a surface-emission laser diode.

Another and more specific object of the
20 present invention is to provide a surface-emission
laser diode or laser diode array having a distributed
Bragg reflector tuned to a wavelength of 1.1μm or
longer wherein the electric resistance of the
distributed Bragg reflector is minimized while
25 maintaining high reflectance.

Another object of the present invention is to provide a surface-emission laser diode or laser diode array in which an intermediate layer is interposed between a high refractive index layer and

5 a low refractive index layer constituting a distributed Bragg reflector with a refractive index intermediate between the high refractive index layer and the low refractive index layer, wherein the thickness of the intermediate layer is optimized for

10 minimizing the resistance of the distributed Bragg reflector while maintaining a high reflectance.

Another object of the present invention is to provide a surface-emission laser diode or laser diode array in which an intermediate layer or

15 heterospike buffer layer is interposed between a low refractive index layer having a wide bandgap and a high refractive index layer having a narrow bandgap with an intermediate bandgap, wherein the compositional profile of Al in the heterospike buffer

20 layer is optimized so as to minimize the resistance of the distributed Bragg reflector while maintaining a high reflectance.

Another object of the present invention is to provide an optical interconnection system or

25 optical telecommunication system using such a

surface-emission laser diode or surface-emission
laser diode array.

Another object of the present invention is
to provide an optical transmission/reception system
5 that uses a long-wavelength surface-emission laser
diode operable at the laser oscillation wavelength of
1.1 - 1.7,m with low operating voltage and small
oscillation threshold current.

Another object of the present invention is
10 to provide an optical transmission/reception system
suitable for construction inside a building by using
a surface-emission laser diode chip in which the
operating voltage is reduced and the threshold
current for laser oscillation is reduced.

15 Another object of the present invention is
to provide a stabilized optical
transmission/reception system by using a long-
wavelength surface-emission laser diode chip
operating stably at the wavelength of $1.1 - 1.7\mu$m
20 for the optical source.

Another object of the present invention is
to eliminate various problems that arise when such an
optical transmission/reception system is actually
incorporated in an electronic apparatus.

25 Another object of the present invention is

to provide a low-cost and energy-saving optical transmission/reception system by using a surface-emission laser diode chip operable at low voltage with a small threshold current of laser oscillation.

5   Another object of the present invention is to facilitate the construction of an optical-fiber telecommunication system that uses a surface-emission laser diode operating at low voltage with low oscillation threshold current as an optical source,

10   by increasing the length of the optical fiber cable extending from a module package beyond a certain length, and hence by improving the productivity of assembling the module package.

Another object of the present invention is

15   to provide an optical-fiber telecommunication system that enables optical transmission of large capacity with low cost, by using a surface-emission laser diode having a reduced operational voltage and reduced oscillation threshold, as an optical source.

20   Another object of the present invention is to provide a reliable optical-fiber telecommunication system by using a surface-emission laser diode having a low operational voltage and low oscillation threshold as an optical source, such that the change

25   of operational characteristic of the laser diode is

suppressed and the lifetime of the laser diode is increased.

Another object of the present invention is to provide an optical telecommunication system realizing excellent optical coupling between a laser diode and an optical fiber, by using a surface-emission laser diode operable at a low operational voltage with low oscillation threshold, for an optical source.

Another object of the present invention is to provide an optical telecommunication system having a simple construction characterized by reduced number of parts and is simultaneously capable of realizing excellent optical coupling as a result of use of a surface-emission laser diode operable at a low operational voltage with low oscillation threshold, for an optical source.

Another object of the present invention is to provide an optical telecommunication system realizing excellent optical coupling between a laser diode and an optical fiber, by using a surface-emission laser diode operable at a low operational voltage with low oscillation threshold, for an optical source.

Another object of the present invention is

to provide an optical telecommunication system
capable of using a laser diode without causing damage
therein, by using a surface-emission laser diode
operable at a low voltage with low threshold current
5   of laser oscillation.

According to the present invention, the
surface-emission laser diode oscillates at the
wavelength band of 1.1 - 1.7 microns suitable for use
in an optical-fiber telecommunications in computer
10   networks or long-range, large-capacity
telecommunication trunks. The surface-emission laser
diode of the present invention oscillates stably at
this wavelength band with low operating voltage and
low oscillation threshold. Conventionally, such a low
15   surface-emission laser diode did not exist. The laser
of the present invention oscillates at the
aforementioned wavelength region with low operational
voltage and low threshold current as a result of use
of an improved semiconductor Bragg reflector. As a
20   result of low power consumption, the surface-emission
laser diode of the present invention successfully
eliminates the heating problem. Thereby, the surface-
emission laser diode of the present invention
oscillates stably. By using such a surface-emission
25   laser diode, it became possible to construct a

practical point-to-point optical transmission/reception system with low cost.

In constructing such a point-to-point optical transmission/reception system, the present invention avoids localized bending of the transmission path. As a result, the optical transmission/reception system connects two points easily and with low cost, without damaging the optical fiber.

Anther object of the present invention to provide a novel and useful semiconductor Bragg reflector as well as a surface-emission laser diode that uses such a semiconductor distributed Bragg reflector, wherein the foregoing problems are eliminated.

Another object of the present invention is to provide a semiconductor distributed Bragg reflector of low resistance and low optical absorption loss without sacrificing the reflectivity. Further, the object of the present invention to provide a surface-emission laser diode, a surface-emission laser array, a surface-emission laser module, an optical interconnection system, and an optical telecommunication system that uses such a semiconductor distributed Bragg reflector.

Another object of the present invention is to provide

a semiconductor distributed Bragg reflector comprising:

5   an alternate stacking of first and second semiconductor layers having respective, different refractive indices; and

a plurality of intermediate layers each sandwiched between a first semiconductor layer and a

10   second semiconductor layer, said intermediate layer having a refractive index intermediate between said refractive indices of said first and second semiconductor layers,

an intermediate layer provided in a region

15   of said semiconductor distributed Bragg reflector having a thickness different from an intermediate layer provided in a different region of said semiconductor distributed Bragg reflector.

In a preferred embodiment of the

20   distributed Bragg reflector, the present invention provides a semiconductor distributed Bragg reflector as set forth above, wherein a difference of bandgap between said first and second semiconductor layers is set smaller in a region of said semiconductor

25   distributed Bragg reflector where said intermediate

layer has an increased thickness than in a region of said distributed Bragg reflector where said intermediate layer has a reduced thickness

In a preferred embodiment of the
5   distributed Bragg reflector, the present invention provides a semiconductor distributed Bragg reflector as set forth above, wherein said intermediate layers have different thickness and different doping concentrations within said semiconductor distributed
10   Bragg reflector, said thickness and doping concentration being changed in correspondence to electric field strength of light within said semiconductor distributed Bragg reflector.

In a preferred embodiment of the
15   semiconductor distributed Bragg reflector, the present invention provides a semiconductor distributed Bragg reflector as set forth above, wherein said intermediate layer has an increased thickness and reduced impurity doping concentration
20   in a region of said semiconductor distributed Bragg reflector where the electric field strength of light is large, and wherein said intermediate layer is formed to have a reduced thickness and increased impurity doping concentration in a region of said
25   semiconductor distributed Bragg reflector where the

electric field strength of light is small.

In a preferred embodiment of the semiconductor distributed Bragg reflector, the present invention provides a semiconductor
5   distributed Bragg reflector as set forth above, wherein said semiconductor distributed Bragg reflector has a design reflection wavelength of 1.1μ m or longer.

According to the present invention, it
10 becomes possible to provide a semiconductor distributed Bragg reflector of low resistance and small optical absorption loss without decreasing the reflectivity in a semiconductor distributed Bragg reflector having an intermediate layer between two
15 semiconductor layers of different refractive indices with a refractive index intermediate of the refractive indices of the above-mentioned two semiconductor layers, by changing the thickness of the intermediate layer in a region of the
20 semiconductor distributed Bragg reflector with respect to the intermediate layers in other regions, as explained before.

Another object of the present invention is to provide a surface-emission laser diode having a
25 semiconductor distributed Bragg reflector, said

semiconductor distributed Bragg reflector comprising:

an alternate stacking of first and second semiconductor layers having respective, different refractive indices; and

5   a plurality of intermediate layers each sandwiched between a first semiconductor layer and a second semiconductor layer, said intermediate layer having a refractive index intermediate between said refractive indices of said first and second

10   semiconductor layers,

an intermediate layer provided in a region of said semiconductor distributed Bragg reflector having a thickness different from an intermediate layer provided in a different region of said

15   semiconductor distributed Bragg reflector.

In a preferred embodiment of the surface-emission laser diode, the active layer contains a group III element of any or all of Ga and In and a group V element of any or all of As, N and Sb.

20   According to the invention, it becomes possible to provide a surface-emission laser diode of reduced optical absorption loss of the oscillation light, low resistance and capable of operating at high output.

25   Another object of the present invention is

to provide a surface-emission laser array comprising a surface-emission laser diode, said surface-emission laser diode having a semiconductor distributed Bragg reflector comprising:

5   an alternate stacking of first and second semiconductor layers having respective, different refractive indices; and

a plurality of intermediate layers each sandwiched between a first semiconductor layer and a

10   second semiconductor layer, said intermediate layer having a refractive index intermediate between said refractive indices of said first and second semiconductor layers,

an intermediate layer provided in a region

15   of said semiconductor distributed Bragg reflector having a thickness different from an intermediate layer provided in a different region of said semiconductor distributed Bragg reflector.

According to the present invention, it

20   becomes possible to provide a highly efficient surface-emission laser array of low optical absorption loss and low resistance and capable of operating at high output power.

Another object of the present invention is

25   to provide a surface-emission laser module comprising

a surface-emission laser diode, said surface-emission

laser diode having a semiconductor distributed Bragg

reflector, said semiconductor distributed Bragg

reflector comprising:

5   an alternate stacking of first and second

semiconductor layers having respective, different

refractive indices; and

           a plurality of intermediate layers each

sandwiched between a first semiconductor layer and a

10   second semiconductor layer, said intermediate layer

having a refractive index intermediate between said

refractive indices of said first and second

semiconductor layers,

           an intermediate layer provided in a region

15   of said semiconductor distributed Bragg reflector

having a thickness different from an intermediate

layer provided in a different region of said

semiconductor distributed Bragg reflector.

           According to the invention, it becomes

20   possible to provide a surface-emission laser module

capable of operating at high output power, having

high electric power transformation efficiency and low

electric power consumption.

           Another object of the present invention is

25   to provide an optical interconnection system

including a surface-emission laser diode having a
semiconductor distributed Bragg reflector, said
semiconductor distributed Bragg reflector comprising:

an alternate stacking of first and second
5   semiconductor layers having respective, different
refractive indices; and

a plurality of intermediate layers each
sandwiched between a first semiconductor layer and a
second semiconductor layer, said intermediate layer
10   having a refractive index intermediate between said
refractive indices of said first and second
semiconductor layers,

an intermediate layer provided in a region
of said semiconductor distributed Bragg reflector
15   having a thickness different from an intermediate
layer provided in a different region of said
semiconductor distributed Bragg reflector.

According to the invention, it becomes
possible to provide an optical interconnection system
20   of high electric power transformation efficiency and
low electric power consumption.

Another object of the present invention to
provide an optical telecommunication system having a
surface-emission laser diode, said surface-emission
25   laser diode having a semiconductor distributed Bragg

reflector, said semiconductor distributed Bragg
reflector comprising:

an alternate stacking of first and second
semiconductor layers having respective, different
5   refractive indices; and

a plurality of intermediate layers each
sandwiched between a first semiconductor layer and a
second semiconductor layer, said intermediate layer
having a refractive index intermediate between said
10   refractive indices of said first and second
semiconductor layers,

an intermediate layer provided in a region
of said semiconductor distributed Bragg reflector
having a thickness different from an intermediate
15   layer provided in a different region of said
semiconductor distributed Bragg reflector.

According to the optical telecommunication
system of the present invention, it becomes possible
to provide an optical telecommunication system of low
20   electric power consumption and high electric power
transformation efficiency.

Accordingly, it is a general object of the
present invention to provide a novel and useful n-
type semiconductor distributed Bragg reflector as
25   well as a surface-emission laser diode, a surface-

emission laser array, a surface-emission laser module, an optical interconnection system and an optical telecommunication system wherein the foregoing problems are eliminated.

5   Another object of the present invention is to provide an n-type semiconductor distributed Bragg reflector as well as a surface-emission laser diode, a surface-emission laser array, a surface-emission laser module, an optical interconnection system and

10   also an optical telecommunication system that uses such an n-type semiconductor distributed Bragg reflector wherein electrostatic capacitance and the influence thereof on the current-voltage characteristic caused by the semiconductor

15   heterointerface is reduced.

Another object of the present invention is to provide an n-type semiconductor distributed Bragg reflector comprising:

first and second semiconductor layers of n-

20   type stacked with each other, said first and second semiconductor layers having respective refractive indices different from each other,

wherein there is provided an intermediate layer between said first and second semiconductor

25   layers, said intermediate layer having a refractive

index intermediate of the refractive indices of said first and second semiconductor layers.

In a preferred embodiment, said intermediate layer has a thickness larger than 20 [nm] in said n-type semiconductor distributed Bragg reflector. In a further preferred embodiment, said intermediate layer has a thickness equal to or larger than 30 [nm] in said n-type semiconductor distributed Bragg reflector.

In a still further preferred embodiment, said intermediate layer has a thickness t [nm] determined with respect to a reflection wavelength λ [um] of said distributed Bragg reflector so as to fall in the ranges of $20 < t \leqq (50\lambda - 15)$ [nm].

Another object of the present invention is to provide a surface-emission laser diode that uses the n-type semiconductor distributed Bragg reflector as set forth above.

Another object of the present invention is to provide a surface-emission laser diode, comprising:

an n-type semiconductor distributed Bragg reflector and a p-type semiconductor distributed Bragg reflector disposed across an active layer,

wherein said n-type semiconductor

distributed Bragg reflector is processed to form a
mesa.

Another object of the present invention is
to provide a surface-emission laser diode comprising:

5   an n-type semiconductor distributed Bragg reflector
and a p-type semiconductor distributed Bragg
reflector disposed across an active layer,

said n-type semiconductor distributed Bragg
reflector having increased resistance as compared

10   with a region forming a cavity of said the surface-
emission laser diode.

In a preferred embodiment, said n-type
semiconductor distributed Bragg reflector comprises
stacking of first and second semiconductor layers

15   having respective, mutually different refractive
indices, said n-type semiconductor distributed Bragg
reflector further comprises an intermediate layer
having a refractive index intermediate of said first
and second semiconductor layer, between said first

20   and second semiconductor layers.

In a preferred embodiment, said n-type
semiconductor distributed Bragg reflector comprises
stacking of first and second semiconductor layers
having respective refractive indices different from

25   each other, said n-type semiconductor distributed

Bragg reflector further including an intermediate
layer having a refractive index intermediate of said
refractive indices of said first and second
semiconductor layers between said first and second
5   semiconductor layers with a thick larger than 20 [nm].

      In a preferred embodiment, said n-type
semiconductor distributed Bragg reflector comprises
stacking of a first and second semiconductor layers
having respective refractive indices different from
10   each other, said n-type semiconductor distributed
Bragg reflector further including an intermediate
layer having a refractive index intermediate of said
first and second semiconductor layers between said
first and second semiconductor layers with a
15   thickness of 30 [nm] or more.

      In a preferred embodiment, said n-type
semiconductor distributed Bragg reflector comprises
stacking of first and second semiconductor layers
having respective refractive indices different from
20   each other, said n-type semiconductor distributed
Bragg reflector further including an intermediate
layer having a refractive index intermediate of said
first and second semiconductor layers, between said
first and second semiconductor layers with a
25   thickness t [nm] determined with respect to a

reflection wavelength λ [um] of said distributed Bragg reflector so as to fall in the ranges of $20 < t \leq (50\lambda - 15)$ [nm].

In a preferred embodiment, said active layer is formed of a group III element and a group V element, said group III element of said active layer being any or all of Ga and In, said group V element of said active layer being any or all of As, N, Sb and P.

Another object of the present invention is to provide a surface-emission laser array comprising a surface-emission laser diode of the type as set forth before.

Another object of the present invention is to provide a surface-emission laser module comprising a surface-emission laser diode or a surface-emission laser array of the type as set forth before.

Another object of the present invention is to provide an optical interconnection system comprising a surface-emission laser diode or a surface-emission laser array or a surface-emission laser module of the type as set forth before.

Another object of the present invention is to provide an optical telecommunication system comprising a surface-emission laser diode or surface-

emission laser array or a surface-emission laser module of the type as set forth before.

According to a first aspect of the present invention it becomes possible to provide an n-type semiconductor distributed Bragg reflector having reduced electrostatic capacitance at the semiconductor heterointerface with the use of the n-type semiconductor distributed Bragg reflector doped to n-type and in which first and second semiconductor layers of different refractive indices are stacked, wherein an intermediate layer having a refractive index intermediate of the first and second semiconductor layers is provided between the first and second semiconductor layers.

The influence of the heterointerface is reduced substantially by setting the thickness of the intermediate layer to be than 20nm, and the current-voltage characteristic of the n-type distributed Bragg is improved. Further, the electrostatic capacitance at the heterointerface can be reduced.

It should be noted that the capacitance of the heterointerface is reduced by the intermediate layer because the accumulation or depletion of the carriers at the interface is suppressed by smoothing the potential distribution such as spike, notch, and

the like, at the heterointerface. In the case that
the intermediate layer is not provided, there is
caused accumulation or depletion of the carriers
(electrons) due to the potential distribution such as
5   spike, notch, and the like, at the heterointerface,
and there arises the problem of non-linearity in the
current-voltage characteristics, such as tunneling of
the carriers through the hetero barrier, or change of
the current-voltage characteristics by the
10   measurement. Furthermore, there arises the problem of
formation of the electrostatic capacitance by the
depletion of the carriers. By providing the
intermediate layer with the thickness of 20 nm or
more to each interface of the n-type distributed
15   Bragg reflector, these problems can be improved
substantially. Thus, by using an intermediate layer
thicker than 20nm, the change of the current-voltage
characteristics and non-linearity of the current-
voltage characteristics by the measurement condition
20   are reduced substantially, and the electrostatic
capacitance caused by the heterointerface is reduced
also substantially. Thus, it becomes possible to
obtain excellent n-type distributed Bragg reflector
with regard to electric characteristics.
25   The influence of the heterointerface is

suppressed more effectively by setting the thickness of the intermediate layer to be 30nm or more, and the current-voltage characteristics of the n-type distributed Bragg reflector can be improve. Further,

5   the electrostatic capacitance at the heterointerface can be reduced.

The reason that the capacity of the heterointerface is reduced by the intermediate layer is because the distribution of the potential such as

10   spike, notch, and the like, at the heterointerface is smoothed by the intermediate layer and accumulation or depletion of the carriers at the interface is suppressed as a result. Thicker the intermediate layer, the effect of the intermediate layer becomes

15   more conspicuous. By setting the thickness of the intermediate layer to be 30nm or more, the difference between the CW measurement and the pulse measurement vanishes more or less, and it becomes possible to achieve the effect mentioned before more effectively.

20   Thus, the change of the current-voltage characteristic and the non-linearity of the current-voltage characteristic are suppressed more effectively. Further, the electrostatic capacitance by the heterointerface can be reduced more

25   effectively, and it becomes possible to obtain an

excellent n-type distributed Bragg reflector with regard to electrical characteristics.

The thickness t [nm] of the above-mentioned intermediate layer is determined in the n-type semiconductor distributed Bragg reflector with regard to the reflection wavelength λ [um] of the distributed Bragg reflector so as to fall in the range of $20 < t \leqq (50\lambda - 15)$ [nm]. Because of this, the influence of the heterointerface is reduced while maintaining high reflectivity and it becomes possible to obtain an n-type distributed Bragg reflector having excellent electric characteristics. In a distributed Bragg reflector, it is possible to obtain higher reflectivity by increasing the refractive-index difference of the semiconductor layers constituting the distributed Bragg reflector and increasing the steepness of the interface. Thus, there is a tendency that the reflectivity gradually falls off with the thickness of the intermediate layer. Accordingly, excessive decrease of thickness of the intermediate layer invites sharp fall off of the reflectivity of the distributed Bragg reflector. However, the effect of smoothing the heterointerface is enhanced with increasing thickness of the intermediate layer. Thus, it will be understood that

there exists an optimum range for the thickness of the intermediate layer in which these requirements are satisfied simultaneously. Thus, optimum thickness range of the intermediate layer is chosen with

5 respect to the reflection wavelength λ [um] of the distributed Bragg reflector as $20 < t \leqq (50\lambda - 15)$ [nm]. With this, it becomes possible to obtain an excellent n-type distributed Bragg reflector having excellent electrical characteristics, in which the influence of

10 the heterointerface was reduced while maintaining high reflectivity.

In another aspect, there is provided a surface-emission laser diode having the n-type semiconductor distributed Bragg reflector as set

15 forth above. Because of this, a surface-emission laser diode having reduced electrostatic capacitance and high speed modulation is obtained.

The surface-emission laser diode includes the n-type semiconductor distributed Bragg reflector

20 and the p-type semiconductor distributed Bragg reflector provided across the active layer, wherein the n-type semiconductor distributed Bragg reflector is processed to the mesa structure. Because of this, electrostatic capacitance is reduced and high speed

25 modulation becomes possible in the surface-emission

laser diode.

It becomes possible to reduce the
electrostatic capacitance and perform high speed
modulation in a surface-emission laser diode
5   comprising an n-type semiconductor distributed Bragg
reflector and a p-type semiconductor distributed
Bragg reflector disposed across an active layer, by
increasing the resistance of the n-type semiconductor
distributed Bragg reflector excluding the region
10   forming a cavity of the surface-emission laser diode.

In another aspect, there is provided a
surface-emission laser diode of the type as set forth
above, wherein the n-type semiconductor distributed
Bragg reflector comprises stacking of first and
15   second semiconductor layers having respective,
mutually different refractive indices, wherein said
n-type semiconductor distributed Bragg reflector
further comprises an intermediate layer having a
refractive index intermediate of said first and
20   second semiconductor layer, between said first and
second semiconductor layers. As a result, the
electrostatic capacitance is reduced and a surface-
emission laser diode capable of performing high speed
modulation is provided.

25   In another aspect, there is provided a

surface-emission laser diode of the type as set forth
above, wherein said n-type semiconductor distributed
Bragg reflector comprises stacking of first and
second semiconductor layers having respective

5   refractive indices different from each other, said n-
type semiconductor distributed Bragg reflector
further including an intermediate layer having a
refractive index intermediate of said refractive
indices of said first and second semiconductor layers

10   between said first and second semiconductor layers
with a thick larger than 20 [nm]. By using the
construction of the foregoing embodiment, it becomes
possible to reduce the area of the n-type
semiconductor distributed Bragg reflector

15   contributing to the electrostatic capacitance by
confining the path of the electrons current, and the
electrostatic capacitance of the heterointerface of
the n-type semiconductor distributed Bragg reflector
is reduced. Thereby, high speed modulation becomes

20   possible. Thus, as explained in relation to the
effect of the invention before, the potential
distribution as the heterointerface is smoothed by
providing the foregoing semiconductor layer to the
heterointerface as compared with the case in which

25   such an intermediate layer is not provided, and

depletion or accumulation of carriers is suppressed.
Thereby, the electrostatic capacitance caused by the
depletion or accumulation of the carriers can be
reduced drastically. Further, by restricting the path
5   of the electrons in the mesa region by etching and
increasing of resistance of the n-type distributed
Bragg reflector as in the case of some embodiments,
the area of the distributed Bragg reflector
contributing to the capacitance is reduced. Thus, by
10   combining these features as in the case of some
embodiment, the electrostatic capacitance of the
device is reduced more effectively, and a structure
very well suited for high speed modulation is
obtained. The device of such an embodiment can
15   perform high speed modulation of 10Gbps or more as a
result of decrease of the electrostatic capacitance
of the n-type distributed Bragg reflector.

    According to another aspect, there is
provided a surface-emission laser diode of the type
20   as set forth above, wherein said n-type semiconductor
distributed Bragg reflector comprises stacking of a
first and second semiconductor layers having
respective refractive indices different from each
other, said n-type semiconductor distributed Bragg
25   reflector further including an intermediate layer

having a refractive index intermediate of said first
and second semiconductor layers between said first
and second semiconductor layers with a thickness of
30 [nm] or more. By using the construction of the

5 tenth embodiment, it becomes possible to reduce the
area of the n-type semiconductor distributed Bragg
reflector contributing to the electrostatic
capacitance by confining the path of the electron
current, and it becomes possible to reduce the

10 electrostatic capacitance of the heterointerface of
the n-type semiconductor distributed Bragg reflector.
Thereby, high speed modulation becomes possible. Thus,
as explained in relation to the effect of the
invention before, it becomes possible to smooth the

15 potential distribution at the heterointerface
sufficiently by providing the foregoing semiconductor
layer to the heterointerface as compared with the
case in which such an intermediate layer is not
provided, and depletion or accumulation of carriers

20 is suppressed. Thereby, the electrostatic capacitance
caused by the depletion or accumulation of the
carriers can be reduced more drastically. Further, by
restricting the path of the electrons in the mesa
region by etching and increasing of resistance of the

25 n-type distributed Bragg reflector as in the case of

some embodiments, the area of the distributed Bragg

reflector contributing to the capacitance is reduced.

Thus, by combining these features as in the case of

some embodiment, the electrostatic capacitance of the

5   device is reduced more effectively, and a structure

very well suited for high speed modulation is

obtained. The device of claim 10 can perform high

speed modulation of 10Gbps or more as a result of

decrease of the electrostatic capacitance of the n-

10   type distributed Bragg reflector.

According to another aspect, there is

provided a surface-emission laser diode of the type

as set forth before, wherein said n-type

semiconductor distributed Bragg reflector comprises

15   stacking of first and second semiconductor layers

having respective refractive indices different from

each other, said n-type semiconductor distributed

Bragg reflector further including an intermediate

layer having a refractive index intermediate of said

20   first and second semiconductor layers, between said

first and second semiconductor layers with a

thickness t [nm] determined with respect to a

reflection wavelength λ [um] of said distributed

Bragg reflector so as to fall in the ranges of $20 < t \leqq$

25   $(50\lambda - 15)$ [nm].

By using the construction of the eleventh
embodiment, it becomes possible to reduce the area of
the n-type semiconductor distributed Bragg reflector
contributing to the electrostatic capacitance by
5   confining the path of the electrons current, and the
electrostatic capacitance of the heterointerface of
the n-type semiconductor distributed Bragg reflector
is reduced. Thereby, high speed modulation becomes
possible. Thus, as explained in relation to the
10   effect of the invention, the potential distribution
as the heterointerface is smoothed by providing the
foregoing semiconductor layer to the heterointerface
as compared with the case in which such an
intermediate layer is not provided, and depletion or
15   accumulation of carriers is suppressed. Thereby, the
electrostatic capacitance caused by the depletion or
accumulation of the carriers can be reduced
drastically. Further, by choosing the thickness of
the intermediate layer to the foregoing range, it
20   becomes possible to maintain the reflectivity of the
n-type distributed Bragg reflector, and a surface-
emission laser diode of low oscillation threshold is
obtained.

Further, by restricting the path of the
25   electrons in the mesa region by etching and

increasing of resistance of the n-type distributed
Bragg reflector as in the case of some embodiments,
the area of the distributed Bragg reflector
contributing to the capacitance is reduced. Thus, by
5 combining these features as in the case of some
embodiment, the electrostatic capacitance of the
device is reduced more effectively, and a structure
very well suited for high speed modulation is
obtained. The device of claim 11 can perform high
10 speed modulation of 10Gbps or more as a result of
decrease of the electrostatic capacitance of the n-
type distributed Bragg reflector.

According to the invention, the active
layer may be formed of a group III element and a
15 group V element, said group III element of said
active layer being any or all of Ga and In, said
group V element of said active layer being any or all
of As, N, Sb and P in the surface-emission laser
diode. Thus, the electrostatic capacitance is reduced
20 and it becomes possible to provide a surface-emission
laser diode of long wavelength band and capable of
performing high speed modulation.

According to another aspect of the
invention, the surface-emission laser array is formed
25 of the surface-emission laser diode of the type noted

before. Thus, the electrostatic capacitance is reduced and it becomes possible to provide a surface-emission laser array capable of performing high speed modulation.

5   According to another aspect of the invention, the surface-emission laser module is formed of a surface-emission laser diode of any of the type noted before or a surface-emission laser array of the type noted before. Thus, a surface-
10 emission laser module capable of performing high speed optical communication and optical transmission is provided.

      According to another aspect of the invention, the optical interconnection system is
15 formed of a surface-emission laser diode of any of the types noted before or a surface-emission laser array of the type noted before or a surface-emission laser module of the type noted before. Thus, an optical interconnection system capable of performing
20 high speed and large capacity optical transmission is provided.

      According to another aspect the invention, the optical telecommunication system is formed of a surface-emission laser diode of the types noted
25 before or surface-emission laser array of the type

noted before or a surface-emission laser module of the type noted before. Thus, an optical telecommunication system capable of performing high-speed and large capacity optical transmission is

5   provided.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram showing a cross-sectional view of a long-wavelength surface-emission

10   laser diode according to a first embodiment of this invention;

Figure 2 is a diagram showing an example of reflection spectrum of a distributed Bragg reflector used in the laser diode of Figure 1;

15   Figure 3 is a cross-sectional view showing the constitution of a semiconductor Bragg reflector used in the long-wavelength surface-emission laser diode of the first embodiment;

Figure 4 is a diagram showing a

20   compositional gradation of a heterospike buffer layer used in the semiconductor Bragg reflector constituting a part of the laser diode of the first embodiment;

Figure 5 is a diagram showing an example of

25   changing an Al composition in the heterospike buffer

layer;

Figure 6 is a diagram showing a result of evaluating a differentiation sheet resistance of the heterospike buffer layer of Figure 4;

5   Figure 7 is a diagram showing the band structure of a distributed Bragg reflector near a heterojunction interface in a thermal equilibrium state;

Figure 8 is a diagram showing the band
10   structure of the heterospike buffer layer of Figure 3 in a thermal equilibrium state;

Figure 9 is a diagram showing an example of the band structure of the heterospike buffer layer used in the present invention;

15   Figure 10 is a diagram showing an example of the band structure of the heterospike buffer layer used in the present invention;

Figure 11 is a diagram showing an example of the band structure of the heterospike buffer layer
20   used in the present invention;

Figure 12 is a diagram showing an example of the band structure of the heterospike buffer layer used in the present invention;

Figure 13 is a diagram showing the
25   relationship between the differential sheet

resistance of the distributed Bragg reflector and the
Al compositional profile in the heterospike buffer
layer;

Figure 14 is another diagram showing the
relationship between the differential sheet
resistance of the distributed Bragg reflector and the
Al compositional profile in the heterospike buffer
layer;

Figure 15 is a diagram showing another band
structure of the heterospike buffer layer;

Figure 16 is a diagram showing the
relationship between the reflectance of the
distributed Bragg reflector and the thickness of the
heterospike buffer layer;

Figure 17 is a diagram showing the
relationship between the resistance of the
distributed Bragg reflector and the thickness of the
heterospike buffer layer;

Figure 18 is another diagram showing the
relationship between the resistivity of the
distributed Bragg reflector and the thickness of the
heterospike buffer layer;

Figure 19 is a further diagram showing the
relationship between the resistivity of the
distributed Bragg reflector and the thickness of the

heterospike buffer layer;

Figure 20 is a further diagram showing another example of the band structure of the heterospike buffer layer;

Figure 21 is a diagram showing the relationship between the resistivity of the distributed Bragg reflector having the heterospike buffer layer of Figure 20 and the thickness of the heterospike buffer layer;

Figure 22 is another diagram showing the relationship between the resistivity of the distributed Bragg reflector having the heterospike buffer layer of Figure 20 and the thickness of the heterospike buffer layer;

Figure 23 is a diagram showing the relationship between the resistance of various distributed Bragg reflectors and the thickness of the heterospike buffer layer;

Figure 24 is another diagram showing the relationship of the resistance of various distributed Bragg reflectors and the thickness of the heterospike buffer layer;

Figure 25 is a diagram showing the relationship between the reflectance of various distributed Bragg reflectors and the thickness of the

heterospike buffer layer;

Figure 26 is another diagram showing the relationship between the reflectance of various distributed Bragg reflectors and the thickness of the

5 heterospike buffer layer;

Figure 27 is a sectional view showing the constitution of the long-wavelength surface-emission laser diode according to a second embodiment of the present invention;

10 Figure 28 is a diagram showing a room temperature photoluminescence spectrum of the active layer formed of a GaInNAs/GaAs double quantum well structure;

Figure 29 is a diagram showing a sample

15 structure;

Figure 30 is a diagram showing a depth profile of nitrogen and oxygen;

Figure 31 is a diagram showing a depth profile of Al;

20 Figure 32 is a diagram showing the structure obtained for a case in which growth interruption process is used in the form of a carrier gas purging process;

Figure 33 is a diagram showing a depth

25 profile of the Al for the case in which a growth

interruption process is provided and purging is conducted by using a hydrogen gas;

Figure 34 is a diagram showing a depth profile of nitrogen and oxygen for the case in which a growth interruption process is provided and purging is made with a hydrogen gas;

Figure 35 is a plane view showing a wafer and a laser diode chip in which the long-wavelength surface-emission laser diode of this invention is formed;

Figure 36 is a diagram showing an example of optical transmission/reception system that connects an optical source and a photodetection unit by a straight the transmission path;

Figure 37 is a diagram showing an overall view of the above optical transmission/reception system; Figure 38 is a diagram showing an example of bending the transmission path connecting an optical source and a photodetection unit at a right angle for avoiding an obstacle;

Figure 39 is a diagram showing an example of the optical transmission/reception system of this invention that avoids an obstacle by bending the transmission path between an optical source and a photodetection unit;

Figure 40 is a diagram showing another example of optical transmission/reception system of this invention that avoids an obstacle between the optical source and the photodetection unit by bending
5   the transmission path;

Figure 41 is a diagram showing an example of an optical transmission/reception system that uses a long-wavelength surface-emission laser diode of this invention as the optical source;

10 Figure 42 is a plane view showing an example of a room in which the optical transmission/reception system of this invention is provided;

Figure 43 is a plane view showing an
15 example of a room in which a conventional optical transmission/reception system is provided;

Figure 44 is a plane view showing a further example of a room in which a conventional optical transmission/reception system is provided;

20 Figure 45 is a schematic diagram showing an example of the optical transmission/reception system of this invention;

Figure 46 is a schematic diagram showing another example of the optical transmission/reception
25 system of this invention;

Figure 47 is a diagram showing an example of the electrophotographic copying machine to which the present invention is applied;

Figure 48 is a diagram showing an example
5 of an electrophotography copying machine that uses an optical transmission/reception system of this invention;

Figure 49 is a diagram showing an example of an ink jet record apparatus to which the present
10 invention is applied;

Figure 50 is a diagram showing an example of the ink jet record apparatus that includes an optical transmission/reception system of this invention;

15 Figure 51 is a diagram showing further example of the optical transmission/reception system of the present invention;

Figure 52 is a diagram showing an example of optical-fiber telecommunication system to which a
20 long-wavelength surface-emission diode according to an embodiment of this invention is connected;

Figure 53 is a diagram showing a bi-directional system constructed by using the long-wavelength surface-emission laser diode of an
25 embodiment and an optical-fiber telecommunication

system connected thereto;

Figure 54 is a diagram showing an example of large capacity optical-fiber telecommunication system that uses plural optical fiber groups in which
5 the long-wavelength surface-emission laser diode of this invention is used;

Figure 55 is a diagram showing a long-wavelength surface-emission laser diode and an optical-fiber telecommunication system connected
10 thereto according to an embodiment of this invention;

Figure 56 is a diagram showing the constitution of an optical connection module used in an optical-fiber telecommunication system together with the a -wavelength surface-emission laser diode
15 according to an embodiment of this invention;

Figure 57 is another diagram showing the constitution of an optical connection module used in an optical-fiber telecommunication system together with a long-wavelength surface-emission laser diode
20 according to an embodiment of this invention;

Figure 58 is a diagram showing another constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an embodiment of this
25 invention;

Figure 59 is a diagram showing the constitution of another optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an

5   embodiment of this invention;

Figure 60 is a diagram explaining the constitution of an optical connection module used in an optical-fiber telecommunication system together with a long-wavelength surface-emission laser diode

10   according to an embodiment of this invention;

Figure 61 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an embodiment of this

15   invention;

Figure 62 is a diagram showing length setting of optical fiber for guiding in an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to

20   a first embodiment of this invention;

Figure 63 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode and plural optical fibers according to an

25   embodiment of this invention;

Figure 64 is a diagram showing an emission angle of an optical beam emitted from a long-wavelength surface-emission laser diode according to an embodiment of the present invention;

5   Figures 65A - 65C are diagrams showing the process of fixing plural optical fibers with a resin according to an embodiment of this invention;

Figures 66A - 66C are diagrams showing a the connect mode of a long-wavelength surface-

10   emission laser diode to plural optical fibers according to an embodiment of this invention;

Figure 67 is a diagram showing possible locations of optical fibers in a closely packed state according to an embodiment of this invention;

15   Figure 68 is a diagram showing an example of arranging plural optical fibers with a closest packed state according to an embodiment of this invention;

Figure 69 is a cross-sectional view showing

20   the constitution of an optical fiber connected to a long-wavelength surface-emission laser diode according to an embodiment of this invention;

Figure 70 is a plane view showing the constitution of the optical-fiber telecommunication

25   system that uses a long-wavelength surface-emission

laser diode and an optical fiber connected thereto according to an embodiment of this invention;

Figure 71 is plane view showing the constitution of a bi-directional optical-fiber

5   telecommunication system that uses a long-wavelength surface-emission laser diode and an optical fiber connected thereto according to an embodiment of this invention;

Figure 72 is a plane view showing the

10   constitution of LAN in a building in which the function of a long-wavelength surface-emission laser diode and the function of an optical fiber connected thereto are separated;

Figures 73A and 73B are respectively a plan

15   view showing a long-wavelength surface-emission laser diode and an integral optical fiber telecommunication apparatus and a cross-sectional view of an optical waveguide according to an embodiment of this invention;

20   Figures 74A and 74B are diagrams showing the constitution of a long-wavelength surface-emission laser diode chip according to an embodiment of this invention;

Figure 75 is a diagram explaining the

25   operation of a semiconductor laser diode chip of

Figures 74A and 74B;

Figures 76A and 76B are diagrams showing the constitution of a long-wavelength surface-emission laser diode chip according to an embodiment

5   of this invention;

Figure 77 is a diagram explaining the operation of a laser diode chip shown in Figures 59A and 59B;

Figure 78 is a diagram showing an optical

10   transmission part of a telecommunication system in which the long-wavelength surface-emission laser diode according to an embodiment of this invention is used;

Figure 79 is a diagram showing an optical

15   transmission part of a telecommunication system in which the long-wavelength surface-emission laser diode of an embodiment of this invention is used;

Figure 80 is a cross-sectional view showing an optical coupling device used in a long-wavelength

20   surface-emission laser diode according to an embodiment of this invention;

Figure 81 is a cross-sectional view showing the optical coupling device of Figure 63;

Figure 82 is a cross-sectional view showing

25   an optical coupling device that couples with a long-

wavelength surface-emission laser diode according to
an embodiment of this invention;

Figure 83 is a cross-sectional view showing
an optical coupling device that couples optically
5   with a long-wavelength surface-emission laser diode
according to an embodiment of this invention;

Figure 84 is a cross-sectional view showing
an optical fiber fixation apparatus used with a long-
wavelength surface-emission laser diode according to
10 an embodiment of this invention;

Figure 85 is a cross-sectional view showing
the structure of an optical coupling device;

Figure 86 is a diagram showing a positional
relationship between a monitor photodetection device
15 and a surface-emission laser diode in an optical-
fiber telecommunication system that uses the long-
wavelength surface-emission laser diode according to
an embodiment of this invention;

Figure 87 is a block diagram showing the
20 constitution of a control circuit that controls
output of a surface-emission laser diode according to
an embodiment of this invention;

Figure 88 is a diagram showing the
constitution of an optical-fiber telecommunication
25 system that uses a long-wavelength surface-emission

laser diode according to an embodiment of this
invention;

Figure 89 is a schematic diagram showing
the constitution of an optical-fiber

5   telecommunication system that uses a long-wavelength
surface-emission laser diode according to an
embodiment of this invention;

Figure 90 is a diagram showing a monitor
photodetection device, a reflection surface and a

10   surface-emission laser diode of an optical-fiber
telecommunication system that uses the long-
wavelength surface-emission laser diode according to
an embodiment of this invention;

Figure 91 is a diagram showing then

15   constitution of an optical-fiber telecommunication
system formed of a long-wavelength surface-emission
laser diode, an optical fiber and an optical
connector according to an embodiment of this
invention;

20   Figure 92 is a diagram showing the
positional relationship between an optical fiber, a
ferule and divided sleeves according to an embodiment
of this invention;

Figure 93 is a diagram showing the

25   relationship between a light emission angle and beam

diameter in a long-wavelength surface-emission laser diode according to an embodiment of this invention;

Figure 94 is a diagram showing the relationship between beam spreading and a core

5   diameter and an optical path length of a long-wavelength surface-emission laser diode according to an embodiment of this invention;

Figure 95 is a diagram showing a calculation example of a relationship between a beam

10   diameter and an optical path length of a long-wavelength surface-emission laser diode according to an embodiment of this invention;

Figure 96 is a diagram showing the constitution of a connection part of a laser diode

15   and an optical fiber of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an embodiment of this invention;

Figures 97A and 97B are diagrams showing

20   the constitution of a connection part of a laser diode and an optical waveguide of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an embodiment of this invention;

25   Figure 98 is a diagram showing the

constitution of a connection part of a laser diode and an optical waveguide in an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an

5   embodiment of this invention;

Figure 99 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode of an embodiment of this invention in

10   which the laser diode and the optical fiber are coupled directly;

Figure 100 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission

15   laser diode according to an embodiment of this invention;

Figure 101 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission

20   laser diode according to an embodiment of this invention;

Figure 102 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission

25   laser diode according to an embodiment of this

invention;

Figure 103 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission

5   laser diode according to an embodiment of this invention;

Figures 104A and 104B are diagrams showing an example of mounting a long-wavelength surface-emission laser diode of an embodiment of this

10 invention;

Figure 105 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an embodiment of this

15 invention;

Figure 106 is a block diagram showing the constitution of a control device used with an optical-fiber telecommunication system according to an embodiment of this invention in which a long-

20 wavelength surface-emission laser diode is used;

Figure 107 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an embodiment of this

25 invention;

Figure 108 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an embodiment of this

5 invention;

Figure 109 is a diagram showing the constitution of an optical-fiber telecommunication system that uses a long-wavelength surface-emission laser diode according to an embodiment of this

10 invention;

Figures 110A and 110B are diagrams showing an emission angle of a laser diode according to an embodiment of this invention;

Figures 111A – 111C are diagrams showing an

15 optical fiber bundle according to an embodiment of this invention;

Figure 112 is a diagram showing an optical fiber bundle according to an embodiment of this invention;

20 Figures 113A and 113B are diagrams showing the cross-section of an optical fiber for multimode transmission according to an embodiment of this invention;

Figure 114 is a diagram showing the cross-

25 section of an optical fiber for single mode

transmission according to an embodiment of this invention;

Figure 115 is a diagram showing the electric current-optical output characteristic of a long-wavelength surface-emission laser diode of an embodiment of this invention for each temperature;

Figure 116 is a diagram explaining the electric current control of a long-wavelength surface-emission laser diode of an embodiment of this invention;

Figure 117 is a diagram showing the constitution of a long-wavelength surface-emission laser diode according to an embodiment of this invention that uses an electric current control;

Figure 118 is a diagram showing the interior of an optical fiber telecommunication apparatus in which a long-wavelength surface-emission laser diode of an embodiment of this invention is provided;

Figure 119 is a diagram showing the constitution of a long-wavelength surface-emission laser diode module according to an embodiment of this invention;

Figure 120 is a diagram showing the constitution of a long-wavelength surface-emission

laser diode according to an embodiment of this
invention;

Figure 121 is a diagram showing the
constitution of a long-wavelength surface-emission

5   laser diode module according to an embodiment of this
invention;

Figure 122 is a diagram showing an example
of laser chip that is used in this invention;

Figure 123 is a diagram showing a different

10 example of laser chip that is used in this invention;

Figure 124 is a diagram showing an example
of system of this invention;

Figure 125 is a diagram showing the
constitution of such a laser chip that explains the

15 system of this invention;

Figure 126 is a diagram showing an example
of control system of this invention;

Figure 127 is a diagram showing a different
example of the control system of this invention;

20   Figure 128 is a diagram explaining the
system of this invention;

Figure 129 is another diagram explaining
the system of this invention;

Figure 130 is a diagram showing the

25 production process of a laser array module that uses

the long-wavelength surface-emission laser diode according to an embodiment of this invention;

Figure 131 is a diagram explaining the quality control process used in the production process of Figure 130;

Figure 132 is a diagram showing an example of the semiconductor distributed Bragg reflector of an embodiment of the present invention;

Figure 133 is a diagram showing an example of the linear compositional graded layer;

Figure 134 is a diagram showing an example of the p-type semiconductor distributed Bragg reflector I of Figure 1;

Figure 135 is a diagram showing an example of the p-type semiconductor distributed Bragg reflector II of Figure 1;

Figure 136 is a diagram showing the resistivity of a p-type semiconductor distributed Bragg reflector designed for the 0.98ₙm band and including 4 pairs therein as a function of the thickness of the compositional graded layer for various Al contents of the low refractive index layer constituting the Bragg reflector;

Figure 137 is a diagram showing the reflectivity of a p-type semiconductor distributed

Bragg reflectors designed for the 0.98„m band and including therein 5 pairs as a function of the thickness of the intermediate layer (compositional graded layer) for various Al contents of the low

5 refractive index layer constituting the Bragg reflector;

Figure 138 is a diagram showing an example of the semiconductor distributed Bragg reflector of an embodiment of the present invention;

10 Figure 139 is a diagram showing the construction of the p-type semiconductor distributed Bragg reflector I of Figure 7;

Figure 140 is a diagram showing the construction of the p-type semiconductor distributed

15 Bragg reflector II of Figure 7;

Figure 141 is a diagram showing an example of the semiconductor distributed Bragg reflector of an embodiment of the present invention;

Figure 142 is a diagram showing the region

20 I of the semiconductor distributed Bragg reflector of Figure 10;

Figure 143 is a diagram showing the region II of the semiconductor distributed Bragg reflector of Figure 10;

25 Figure 144 is a diagram showing an example

of the semiconductor distributed Bragg reflector of an embodiment of the present invention;

Figure 145 is a diagram showing the region I of the semiconductor distributed Bragg reflector of
5   Figure 13;

Figure 146 is a diagram showing the region II of the semiconductor distributed Bragg reflector of Figure 13;

Figure 147 is a diagram showing the
10   reflectivity of a semiconductor distributed Bragg reflector designed for the reflection wavelength of 1.3„m and including 5 pairs therein as the function of the thickness of the compositional graded layer for various Al contents of the low refractive index
15   layer;

Figure 148 is a diagram showing an example of the surface-emission laser diode of an embodiment of the present invention;

Figure 149 is a diagram showing an example
20   of the surface-emission laser diode produced by conducting a crystal growth process on a p-type semiconductor substrate;

Figure 150 is a diagram that showing an example of the surface-emission laser array of an
25   embodiment of the present invention;

Figure 151 is a diagram showing an example of the surface-emission laser module of an embodiment of the present invention;

Figure 152 is a diagram showing a parallel optical interconnection system as an example of an embodiment of the present invention;

Figure 153 is a diagram showing an optical LAN system as an example of the optical telecommunication system of an embodiment of the present invention;

Figure 154 is a diagram showing an example of the n-type semiconductor distributed Bragg reflector according to an embodiment of the present invention;

Figure 155 is a diagram showing an example of the compositional graded layer;

Figure 156 is a diagram showing an example of an embodiment of the present invention;

Figure 157 is a diagram showing an example of an embodiment of the present invention;

Figure 158 is a diagram showing an example of the n-type semiconductor distributed Bragg reflector;

Figure 159 is a diagram showing an example of the surface-emission laser diode according to an

embodiment of the present invention;

Figure 160 is a diagram showing an example of the n-type semiconductor distributed Bragg reflector;

5   Figure 161 is a diagram showing an example of realizing the surface-emission laser diode on a p-type semiconductor substrate;

Figure 162 is a diagram showing another example of the surface-emission laser diode;

10   Figure 163 is a diagram showing an example of the surface-emission laser array according to an embodiment of the present invention;

Figure 164 is a diagram showing an example of the surface-emission laser diode module according

15   to an embodiment of the present invention;

Figure 165 is a diagram showing a parallel optical interconnection system as an example of the optical interconnection system of an embodiment of the present invention;

20   Figure 166 is a diagram showing an optical LAN system as an example of an optical telecommunication system of an embodiment of the present invention;

Figure 167 is a diagram showing a current-

25   voltage characteristic for showing the effect of the

heterointerface on the device characteristics;

Figure 168 is a diagram showing a device including the n-type semiconductor distributed Bragg reflector formed of AlAs/GaAs;

5   Figure 169 is a diagram showing the current-voltage characteristics of the device having a structure similar to that of Figure 168 in which a linear composition al graded layer is provided to each AlAs/GaAs interface of the n-type semiconductor

10   distributed Bragg reflector;

Figure 170 is a diagram showing the differential coefficient of reflectivity change with regard to the thickness of the compositional graded layer of the distributed Bragg reflector formed of

15   AlAs/GaAs for various wavelength bands;

Figure 171 is a diagram showing an example of the n-type distributed Bragg reflector of an embodiment of the present invention.

20   <u>DETAILED EXPLANATION OF PREFERRED EMBODIMENTS</u>

[First Embodiment]

First, a light-emitting device used in an optical-fiber telecommunication system of this invention will be explained with reference to Figure

25   1.

Figure 1 shows an example of a long-wavelength surface-emission laser diode that oscillates at the wavelength of 1.1 - 1.7 μm in which the transmission loss becomes minimum.

5   As explained before, while there have been some suggestions about the possibility of long-wavelength surface-emission laser diode that oscillating at the wavelength of 1.1 - 1.7 μm, there have been no knowledge available with regard to the

10   material and constitution for the realization such a laser diode.

This invention provides concrete constitution of such a long-wavelength surface-emission laser diode that uses a material of GaInNAs

15   system for the active layer.

In this invention, a high refractive index layer and a low refractive index layer of n-type AlGaAs respectively having a composition represented by $Al_xGa_{1-x}As$ (x=1.0) and $Al_yGa_{1-y}As$ (y=0) are

20   stacked on an n-type GaAs substrate 11 having a (100) surface orientation alternately and repeatedly for 35 periods with a thickness $\lambda/4$ for each layer, wherein the $\lambda/4$ thickness is a thickness of 1/4 times the oscillation wavelength λ of the laser diode. As a

25   result, an n-type semiconductor Bragg reflector

(AlAs/GaAs lower semiconductor Bragg reflectors) 12 is formed on the GaAs substrate 11.

Next, an n-type GaInPAs layer 13 having a composition represented as GaxIn1-xPyAs1-y (x=0.5,
5   y=1), is provided on the Bragg reflector 12 with a thickness of λ/4. In this example, this n-type GaxIn1-xPyAs1-y (x=0.5, y=1) layer 13 also constitutes one of the low refractive index layers that forms a part of the lower part reflector 12.

10   Further, a lower part spacer layer 14 of undoped GaAs is formed on the GaInPAs layer 13, and an active layer 15 having a multiple quantum well structure, in which three quantum well layers 15a each having a composition represented as GaxIn1-xAs
15   are stacked on the lower part spacer layer 14 with a GaAs barrier layer 15b having a thickness of 20nm interposed therebetween. Further, an upper part spacer layer 16 of undoped GaAs is provided on the active layer 15. The active layer 15 forms a
20   resonator 15R having a thickness λ corresponding to one full wavelength of oscillation wavelength of the laser diode together with the upper and lower spacer layers 14 and 16. It should be noted that the resonator 15R constitutes the active region of the
25   surface-emission laser diode.

In the constitution of Figure 1, a p-type GaInPAs layer 17 doped with C (carbon) and having a composition of GaxIn1-xPyAs1-y (x=0.5, y=1) is formed further on the spacer layer 16. Further, a Zn-doped

5   GaAs layer having a composition of AlxGa1-xAs (x=0) and a Zn-doped AlAs layer having a composition represented as AlxGa1-xAs (x=1.0) are formed on the p-type GaInPAs layer 17 alternately with a thickness of 1/4 times the oscillation wavelength λ in each

10   medium, to form a periodical structure (one period).

Further, a semiconductor Bragg reflector 18 is formed thereon by stacking a C-doped, p-type AlGaAs layer having a composition represented as AlxGa1-xAs (x=0.9) and a Zn-doped, p-type GaAs having

15   a composition represented as AlxGa1-xAs (x=0) alternately each with a thickness of 1/4 times the oscillation wavelength λ of the laser diode in each medium, to form a periodic structure (25 periods). In this example, the p-type GaInPAs layer 17 also forms

20   one of the low refractive index layers constituting a part of the upper part reflector.

In this embodiment, each of the upper part reflector 18 and the lower part reflector 12 has the constitution of stacking a low refractive index layer

25   and a high refractive index layer alternately,

wherein it should be noted that a heterospike buffer
layer having a composition represented as AlzGa1-zAs
(0≦y<z<x≦1) and a refractive index intermediate
between the low refractive index layer and the high
5   refractive index layer is interposed in this
invention between the low refractive index layer and
the high refractive index layer as shown in Figure 3.
· More precisely, in the structure of Figure 3, the
thickness of the intermediate layer, the low
10   refractive index layer and the high refractive index
layer are set such that the change of the oscillation
wavelength in the part of the intermediate layer and
the high refractive index layer and the oscillation
wavelength in the remaining part of the intermediate
15   layer and the low refractive index respectively
become $\lambda/4$.

       Hereinafter, description will be made about
the constitution of the reflector of the present
invention that reflects the wavelength of 1.1ₙm or
20   more in detail with reference to Figure 3.

       Figure 3 shows a part of the semiconductor
Bragg reflector 18. A similar constitution is formed
also for the semiconductor Bragg reflector 12. In the
description below, explanation for the Bragg
25   reflector 12 will be omitted in view of the

essentially same constitution of the reflector 18 and the reflector 12.

Figure 2 shows an example of the reflection spectrum of the reflector in which a structural unit
5 of AlAs/GaAs is repeated 24 times (24 pairs). In the example of Figure 2, each of the AlAs layers is formed to have a thickness of 93.8 nm and each of the GaAs layers is formed to have a thickness of 79.3 nm, wherein it should be noted that these thicknesses are
10 chosen so as to be equal to 1/4n wavelength of the optical radiation that has a wavelength of 1.1 μm in the vacuum environment. Here, n represents the refractive index of each of the AlAs layer and the GaAs layers. By setting the thickness of the layers
15 constituting the distributed Bragg reflector to be equal to 1/4n times of a given wavelength λ, it is possible to tune the reflector to this wavelength λ, and the distributed Bragg reflector thus tuned shows a large reflectance in the wide wavelength band
20 including the foregoing tuned wavelength λ. This wavelength λ will be referred to as designed wavelength.

It should be noted that the material of the AlGaAs system has various advantages for the material
25 of the distributed Bragg reflector. For example, the

AlGaAs material can be grown on a commonly available low-cost GaAs substrate with lattice matching. Further, the material has excellent heat radiation capability as compared with other semiconductor

5   materials. Furthermore, by using the material system of AlGaAs, it becomes possible to secure a large diffractive index as compared with the case of using other material systems. For example, a refractive index difference of 0.5 is realized between the end

10   member compositions AlAs and GaAs that constitute the AlGaAs system at the wavelength of 1.3 μm. Thus, it becomes possible to achieve a large reflectance with reduced number of stacked pairs as compared with the case of using other material system.

15   Figure 3 shows the construction of the distributed Bragg reflector constituting the upper reflector 18 or lower reflector 12 of the laser diode of Figure 1.

       Figure 3 is referred to.

20   In the present embodiment, each of the upper and lower reflectors 18 and 12 is formed of a distributed Bragg reflector having a reflection wavelength of 1.1 μm or more and has a construction of stacking a lower refractive index layer 18a and an

25   upper refractive index layer 18b, wherein it can be

seen that there is provided a heterospike buffer layer 18c of AlxGal-xAs ($0 \leqq y < z < z \leqq 1$) having a refractive index intermediate between the refractive index of the low refractive index layer 18a and the

5   high refractive index layer 18b.

Such a heterospike buffer layer has been studied in relation to the laser diode of 0.85μm band. However, it is still in the stage of feasibility study and no detailed study has been made

10   with regard to the material, thickness, and like of the heterospike buffer layer. Further, there has been no proposal at all about such a heterospike buffer layer in relation to the long-wavelength surface-emission laser diode of $1.1 - 1.7 \mu$m band as in the

15   case of this invention. This is because the long-wavelength surface-emission laser diode of $1.1 - 1.7$ μm band itself is a new field and few researches have been made so far.

The inventor of this invention noticed the

20   usefulness of optical telecommunication technology that uses a long-wavelength surface-emission laser diode of $1.1 - 1.7 \mu$m band and devotedly conducted a study so as to realize such a laser diode.

Such a heterospike buffer layer 18c is

25   formed at the time of formation of the semiconductor

Bragg reflector 12 or 18 by an MOCVD process, by
controlling the source gas flow rate, such that the
Al content in the AlGaAs film forming the heterospike
buffer layer changes continuously or stepwise. With
5   this, the refractive index of a film changes also
continuously or stepwise.

In more detail, the supply rate of Ga and
Al is changed such that the value of the
compositional parameter z is changed in the $Al_zGa_{1-z}As$
10   $(0 \leq y < z < x \leq 1)$ layer from 0 to 1.0, at the time of
the formation of the AlGaAs film 18c. With this, the
film composition of the heterospike buffer layer
changes gradually from GaAs to AlGaAs to AlAs. Such a
change of the supply rate is caused by controlling
15   the gas flow rate at the time of the formation of
film 12c as noted before. A similar effect is
obtained when the ratio of Al and Ga is changed
stepwise or continuously.

The reason that such a heterospike buffer
20   layer is provided is to eliminate the problem of
increased resistance, which appears in a
semiconductor Bragg reflector, particularly in a p-
type semiconductor Bragg reflector such as the Bragg
reflector 18. Such increase of electric resistance is
25   caused as a result of hetero barrier formed at the

hetero interface where two different semiconductor
layers of the semiconductor Bragg reflector make a
contact. By changing the Al composition gradually at
the hetero interface from the low refractive index
5   layer to the high refractive index layer as in the
case of this invention, there is also caused a
corresponding gradual change of refractive index at
the hetero interface. In this way, the occurrence of
the hetero barrier at the hetero interface is
10 successfully suppressed.

Hereinafter, more detailed explanation will
be made about such a heterospike buffer layer with
reference to Figure 4.

Figure 4 shows an example of the
15 semiconductor Bragg reflector 18 provided with the
heterospike buffer layer 18c between two
semiconductor layers 18a and 18b constituting the
semiconductor Bragg reflector. It should be noted
that Figure 4 shows the case of using the
20 semiconductor material $Al_zGa_{1-z}As$ $(0 \leqq y < z < x \leqq 1)$ of
the AlGaAs system for the material of the
semiconductor Bragg reflector.

The two semiconductor layers 18a and 18b
constituting the semiconductor Bragg reflector 18 of
25 Figure 4 are AlAs and GaAs, and a compositional

gradation layer changing the Al content gradually therein is provided between the layers 18a and 18b as the heterospike buffer layer. The heterospike buffer layer thus formed has valence band energy

5 intermediate between the valence band energy of AlAs and the valence band energy of GaAs. Thus, the ratio of Al to Ga is changed from GaAs to AlGaAs to AlAs in the heterospike buffer layer, and the value of z of the $Al_zGa_{1-z}As$ ($0 \leqq y < z < x \leqq 1$) heterospike buffer layer

10 is changed gradually from 0 to 1.0.

In the semiconductor material of the AlGaAs system, the bandgap energy increases with the Al content and the refractive index falls off with the Al content. In the conduction band, there occurs an

15 increase of band energy until the Al content x reaches 0.43, and the band energy starts to decrease thereafter. In the valence band, on the other hand, the valence band energy falls off monotonously with the increment of the Al content x. In total, the

20 bandgap energy increases with the Al content x.

In the case of the quaternary system of AlGaInP, a similar trend as in the case of increasing the Al content in the AlGaAs system appears with increase of the AlInP composition, and the conduction

25 band energy increases up to the point in which the

AlInP composition has reached 0.7. Thereafter, the conduction band energy starts to decrease. On the other hand, the valence band energy decreases monotonously with the increase of AlInP composition.

5   In the example of Figure 4, it should be noted that the rate of the compositional gradation (rate of increase of bandgap energy) is set larger in the region near the GaAs layer (region I in Figure 4) as compared with the region near the AlAs layer

10   (region II in Figure 4). For the purpose of comparison, a structure having a linear compositional gradation layer, in which the Al content therein is changed only linearly, for the heterospike buffer layer 18c is shown in Figure 5.

15   Figure 6 shows the result of evaluation of the electric resistance of the p-type distributed Bragg reflector 18 tuned to the reflection wavelength of 1.3μm, wherein the Bragg reflector 18 is formed by repeating the AlAs/GaAs unit structure, including

20   therein the heterospike buffer layer of 20nm thickness between the AlAs layer 18a and the GaAs layer 18b, four times (four pair stacking).

        In Figure 6, each of the layers 18a - 18c of the distributed Bragg reflector 18 including the

25   heterospike buffer layer 18c is formed of a p-type

layer having a career density of 1×10^{18} cm^{-3}, and the vertical axis of Figure 6 represents the value of differential sheet resistance at near zero bias state. On the other hand, the horizontal axis of Figure 6

5   represents the Al compositional gradation in the region I. It should be noted that the "Al compositional gradation" is defined as the change of the Al content in the region I divided by the thickness of the region I. Thus, Figure 6 represents

10   the case in which the thickness of the region I is changed variously, while it should be noted that the total thickness of the region I and the region II is maintained constant at 20nm. Thus, the thickness and the compositional gradation of the region II are

15   determined by the thickness and the compositional gradation of the region I. The Al compositional gradation for the case a simple linear compositional gradation layer is provided between the GaAs layer and the AlAs layer becomes 0.05nm^{-1}. This hits the A

20   point of the drawing.

From Figure 6, it can be seen that the resistance is reduced further by increasing the Al compositional gradient in the heterospike buffer layer 18c from the region II to the region I as

25   compared with the case of Figure 5 in which the

compositional gradation is linear throughout the
heterospike buffer layer 18c. Also, it can be seen
that there exists an optimum Al compositional
gradation in which the resistance becomes minimum.

5   For example, in the case the thickness of the region
I is 10nm (the same thickness as the region II), it
can be seen that the resistance is reduced to about
80% of the conventional resistance value obtained for
the case in which the Al compositional gradation is

10 set to $0.09nm^{-1}$. This trend does not change depending
on the applied voltage.

Next, the reason of this will be explained.

Figure 7 shows the valence band structure
of the distributed Bragg reflector having the

15 AlAs/GaAs structure for the part near the hetero
surface in thermal equilibrium state.

Figure 7 is referred to.

It can be seen that the heterospike
originating from the band discontinuity appear

20 predominantly at the side of the widegap AlAs layer.
In the side of the GaAs layer, the occurrence of the
notch is trifling. Thus, the notch at the side of the
GaAs layer does not become the cause of increase of
resistance. Therefore it is concluded that, for the

25 reduction of resistance of a distributed Bragg

reflector, it is important to eliminate or reduce the heterospike appearing at the side of the AlAs layer within a limited thickness of the heterospike buffer layer.

5   In the structure of Figure 7, it can be seen that the Al content of the heterospike buffer layer 18c is increased sharply at the side of the GaAs layer 18b in which there occurs the notch formation, while this corresponds to a gentle

10 compositional gradient at the side of the AlAs layer, in side which the remarkable heterospike formation takes place. By doing so, it becomes possible to reduce the spike formation as compared with the case of changing the composition of the heterospike buffer

15 layer linearly as in the case of Figure 5. When the Al compositional gradation is set smaller in the region I with regard to the region II, on the other hand, there occurs an unwanted increase of resistance.

      Figure 8 shows the valence band diagram of

20 the structures of Figures 3 and 4 in a thermal equilibrium state, wherein the continuous line represents the band structure of Figure 3 while the dotted line represents the band structure of Figure 4.

      Figure 8 is referred to. By using the

25 compositional gradation profile of Figure 4, it

becomes possible to reduce the compositional
gradation of the heterospike buffer layer 18c in the
region II at the side of the AlAs layer 18a with
regard to the region I at the side of the GaAs layer
5   18b as compared with case of using the simple
compositional gradation of Figure 5 with the same
thickness. Thus, it is concluded that the resistance
of the semiconductor distributed Bragg reflector is
reduced by increasing the compositional gradation in
10   the region I of the heterospike buffer layer I.

In the example of Figure 4, it can be seen
that the heterospike buffer layer 18c is formed of
two regions I and II each having a linear Al
compositional profile. On the other hand, it is also
15   possible to change the Al content non-linearly as
represented in Figure 9. Even in such a case, it is
possible to define the boundary between the regions I
and II as an intersection of the intercept drawn to
the valence band at the boundary between the GaAs
20   layer 18b and the heterospike buffer layer 18c and
the intercept drawn also to the valence band at the
boundary between the AlAs layer 18a and the
heterospike buffer layer 18c, as represented in
Figure 9.

25   In the heterospike buffer layer 18c, it is

not necessary that the Al composition changes
continuously but another layer may exist between the
regions I and II as represented in Figure 10.

According to Figure 6, the differential
5   sheet resistance of the Bragg reflector is reduced
with decreasing thickness of the region I. Further,
it can be seen that the minimum of the differential
sheet resistance is achieved when there is no region
I provided as represented in Figure 11 or when the
10   thickness of the region I is small enough that it can
be regarded that there is a discontinuity in the
conduction band between the GaAs layer 18b (narrow
gap layer) and the heterospike buffer layer 18c
(widegap layer) as represented in Figure 12.

15   Figure 13 shows the differential sheet
resistance of the distributed Bragg reflector similar
to the one shown in Figure 6 as a function of the Al
compositional gradation in the region II. It should
be noted that the Al compositional gradation in the
20   region II is determined uniquely from the Al
compositional gradation in the region I and the
thickness of the region I.

From Figure 13, it can be seen that there
appears a minimum of the differential sheet
25   resistance at a particular value of the compositional

gradation in the layer 11, wherein this particular
value of the compositional gradation is irrelevant to
the thicknesses of the regions I and II.

Figure 14, on the other hand, shows a
5   similar relationship as the case of Figure 13 for the
case the total thickens of the regions I and 11 is 40
nm.

Referring to Figure 14, it can be seen that
a similar minimum of resistance appears at a
10   particular value of the Al compositional gradation.

From Figures 13 and 14, it is possible to
evaluate the optimum discontinuity of valence band
energy between the narrow gap layer (GaAs layer 18b
of Figure 3) and the heterospike buffer layer 18c for
15   minimizing the resistance of the distributed Brag
reflector having a heterospike buffer layer.

As noted above, in the semiconductor
distributed Bragg reflector having a heterospike
buffer layer, it is possible to minimize the
20   resistivity of the reflector by changing the Al
composition of the heterospike buffer layer sharply
in the region I and optimizing the Al compositional
gradation in the region II correspondingly, such that
there appears a discontinuity or substantial
25   discontinuity at the boundary between the narrow gap

layer 18b and the heterospike buffer layer 18c.

For example, it is possible to reduce the resistance of the distributed Bragg reflector by about 75% by reducing the thickness of the region I to 1 nm in the heterospike buffer layer 18c having a thickness of 20 nm, as compared with the distributed Bragg reflector having a heterospike buffer layer of the same thickness except that the Al composition is changed linearly throughout the heterospike buffer layer.

In this case, too, it is not necessary that the Al content changes linearly in the regions I and II of the heterospike buffer layer 18c but the Al content may be changed non-linearly as represented in Figure 15.

Further, it should be noted that the foregoing consideration is not limited to the distributed Bragg reflector of the AlGaAs system but is applicable also to the distributed Bragg reflector of other material systems such as AlGaInP system. In the case of the distributed Bragg reflector of the AlGaInP system, it is possible to achieve a similar effect by changing the AlInP composition in the heterospike buffer layer.

The present invention has a feature in that

the main layer 18a or 18b and the heterospike
relaxation layer 18c constituting the semiconductor
distributed Bragg reflector of FIG.3, have a carrier
density in the range from $5 \times 10^{17} cm^{-3}$ to $2 \times 10^{18} cm^{-3}$,

5   the heterospike relaxation layer 18c has a thickness
in the range from 5nm to 40nm, and the average change
rate of Al composition in the region II (see FIG.4)
is in the range from $0.02 nm^{-1}$ to $0.15 nm^{-1}$. Here, the
Al compositional gradient in the region I is defined

10   as "Al compositional gradient = {variation (0-1) of
Al content in the region I}/dI". By choosing each
parameter of the heterospike buffer layer 18c that
includes the distributed Bragg reflector to the
foregoing range, reduction of resistance is achieved

15   easily and effectively.

Table 12 below shows the Al composition
gradient that provides minimum of the electric
resistance and the corresponding sheet differential
resistance for the case of changing the carrier

20   density of the distributed Bragg reflector and the
heterospike buffer layer 18c ($5 \times 10^{17} cm^{-3}$, $2 \times 10^{18} cm^{-3}$) and the thickness of the heterospike buffer layer
12 in the structure of FIG.9, together with the
percentage of the electric resistance decrease in

25   comparison with the case in which a simple linear

compositional gradient is used for the heterospike
buffer layer (the structure of FIG.5).

Table 12

Heterospike buffer layer thickness	$5 \times 10^{17}[cm^{-3}]$ carrier density	$2 \times 10^{18}[cm^{-3}]$ carrier density
5 [nm]	$0.16[nm^{-1}]/8.4\times10^{-6}[\Omega cm^2]/83\%$	$0.16/4.5\times10^{-8}[\Omega cm^2]/90\%$
40 [nm]	$0.02[nm^{-1}]/2.1\times10^{-9}[\Omega cm^2]/91\%$	$\cdots$

5

        In view of increase of electrical
resistance with decrease of the carrier density, the
value of $5 \times 10^{17} cm^{-3}$ is chosen as the actually
allowable lower limit. Further, a value of $2 \times 10^{18} cm^{-3}$
10 is chosen as the allowable upper limit in view of
conspicuous optical absorption particularly in the
case of a p-type semiconductor.
        In the case the thickness of the
heterospike buffer layer 12 is increased, a
15 remarkable decrease of resistance is achieved. On the
other hand, such a decrease of the thickness of the

heterospike buffer layer 12 is not preferable in view of decrease of reflectance of the distributed Bragg reflector. From the viewpoint of reflectance, it is believed that the value of 40nm or less is important

5   for the practical thickness of the heterospike buffer layer.

In the case the thickness is too small, the desired resistance decrease is not attained. Thus, it is believed that the value of 5nm or more is

10 important for the thickness of the heterospike buffer layer 12 for realizing sufficient resistance reduction effect.

As compared with the case of the simple compositional gradation layer in which the Al content

15 is changed linearly from the small-bandgap layer to the large-bandgap layer constituting the main layers of the distributed Bragg reflector, the foregoing construction can achieve further reduction of the resistance. Within the foregoing range, the

20 differential sheet resistance is decreased to about 75% (1.2 x $10^{-9}\Omega cm^2$ in terms of differential sheet resistance) in the embodiment of claim 3, and thus a significant effect is achieved.

Thus, the present embodiment can reduce the

25 resistance further as compared with the case of using

the linear compositional gradient in the heterospike

buffer layer 18c of the same thickness. In the case

of achieving the same resistance value, on the other

hand, the present embodiment allows the use of

5   reduced thickness for the necessary heterospike

buffer layer 18c. Thus, adversary effect on the

optical properties such as reflectance is minimized.

Thus, it becomes possible to obtain a

distributed Bragg reflector excellent in terms of

10   electric properties and optical properties, by

choosing the structure of the distributed Bragg

reflector and heterospike buffer layer as set forth

in the claims.

Next, the optimum thickness of such a

15   heterospike buffer layer $Al_zGa_{1-z}As$ ($0 \leqq y < z < x \leqq 1$)

will be described.

Figure 16 shows the relationship between

the reflectance and thickness of the heterospike

buffer layer for a distributed Bragg reflector tuned

20   to the $0.88 \mu m$ band and $1.3 \mu m$ band for the case the

heterospike buffer layer 18c has a linear

compositional profile of Al as represented in Figure

5. The reason that the reflector tuned to the

conventional wavelength of $0.88 \mu m$ was prepared in

25   this experiment is to make a comparison with a

conventional reflector tuned to this wavelength. It should be noted that GaAs absorbs optical radiation shorter than 0.87μm. In Figure 16, GaAs is used for the high refractive index layer and AlAs is used for

5   the low refractive index layer.

The distributed Bragg reflector thus produced needed 18 pairs or more of the low refractive index layer and the high refractive index layer in order to achieve the reflectance exceeding

10   99.9% at the wavelength band of 0.88μm, while 23 pairs or more were needed for achieving the same reflectance at the wavelength band of 1.3μm. It should be noted that Figure 16 represents the relationship between the reflectance and thickness of

15   the heterospike buffer layer of the distributed Bragg reflector tuned to the respective wavelengths.

Table 1 summarizes the reflectance of Figure 16.

TABLE 1

	0 nm	5 nm	10 nm
0.88μm band	99.914	99.912	99.905
1.3μm band	99.923	99.923	99.920

20   Referring to Table 1, it can be seen that there is no decrease of reflectance in the 1.3μm band until the thickness of the heterospike buffer

layer 18c reaches 5 nm. In the 0.88μm band, on the
other hand, there starts a decrease of reflectance at
the thickness of 5 nm of the heterospike buffer layer
18c. In the case of a surface emission laser diode,

5 the cavity length is characteristically small and the
effect of reflection loss by the mirror appears
conspicuously. Thus, even in the case the decrease of
the reflectance is very small, a large effect is
caused in the threshold current of the laser diode.

10   Figures 17 and 18 show the resistivity of
the AlAs/GaAs distributed Bragg reflector, having the
heterospike buffer layer 18c similar to Figure 5 and
tuned to the reflection wavelength of 1.3μm, near
the zero bias point. In the drawings, the resistivity

15 is represented in terms of $\Omega\,cm^2$ and is defined as
dV/dJ (V: voltage represented in terms of volts; J:
current density represented in terms of A/cm^2). In
the illustrated example, the number of pairs is four.
It should be noted that Figure 17 and Figure 18 shows

20 essentially the same diagram except that Figure 17
shows the diagram in the logarithmic representation
while Figure 18 shows the diagram in the linear scale
representation. In Figures 17 and 18, the broken line
represents the resistivity evaluated from the bulk

25 crystal resistivity, neglecting the effect of the

band discontinuity. Further, each layer of the distributed Bragg reflector is doped to the p-type with the carrier density of $1 \times 10^{16} cm^{-3}$.

Referring to Figure 17, it can be sent hat
5   the resistivity of the distributed Bragg reflector decreases with the thickness of the heterospike buffer layer 18c. In the case of the reflector tuned to the wavelength of $1.3 \mu m$, the proportion of the compositional gradation layer 18c with regard to the
10 rest of the layers 18a and 18b is relatively small. Thus, it becomes possible to reduce the resistivity by two orders by providing the heterospike buffer layer 18c with the thickness of 5nm, without causing influence to the reflectance. Longer the reflection
15 wavelength, the heterospike buffer layer 18c can be formed with increased thickness. When the thickness is smaller than 5 nm, on the other hand, the desired reduction of the resistance is not obtained as can be seen from Figure 17.

20   As represented in Figure 17, the distributed Bragg reflector shows a very high resistivity value of $1 \ \Omega cm^2$ when the heterospike buffer layer 18c is omitted. Thus, in the matter of practical problems, it is extremely difficult to
25 drive a laser diode having a distributed Bragg

reflector in which 20 or more stacks are provided. In order to drive such a laser diode, a very high voltage would be needed. Thus, it is difficult to apply such a distributed Bragg reflector to a current

5   driven device such as a surface-emission laser diode.

In the case of providing the heterospike buffer layer 18c with the thickness of 5 nm as noted above, the resistance of the reflector is reduced by two orders as compared with the case not providing

10   such a heterospike buffer layer. As a result, supply of the drive current to the laser diode is facilitated and laser oscillation becomes possible. Further, the necessary drive voltage is reduced, and the problems such as failure or malfunctioning of the

15   laser diode or reliability are resolved. As represented in Table 1, there is no decrease of reflectance. Thus, the laser oscillation can be achieved at a low threshold current density.

Thus, the foregoing thickness of 5 nm is

20   thought as being the lower limit of the heterospike buffer layer that enables decrease of resistance without causing problems to the reflection performance at long wavelengths. Therefore, the heterospike buffer layer 18c should be formed with a

25   thickness of 5 nm or more.

By increasing the thickness of the
heterospike buffer layer 18c, the resistivity falls
of sharply, and with this, the drive voltage and the
heat generation of the device are reduced. Associated
5   with this, the operational temperature range of the
laser diode is extended and the laser output is
increased.

In the case of allowing 99.8% reflectance
for the distributed Bragg reflector, the maximum
10   thickness of the heterospike buffer layer that can be
provided to the distributed Bragg reflector tuned to
the 0.88μm wavelength is limited to 20nm or less. In
the case of the distributed Bragg reflector tuned to
the 1.3μm, it is possible to provide the heterospike
15   buffer layer 18c up to the thickness of 50 nm.

As represented in Figure 6, the resistance
of the distributed Bragg reflector decreases with the
thickness of the heterospike buffer layer 18c up to
the thickness of 50 nm for the heterospike buffer
20   layer 18c, and a resistivity of 1.05 times the bulk
resistivity is achieved at the thickness of 50 nm for
the layer 18c. When the thickness of·the heterospike
buffer layer 18c is increased further, on the other
had, there appears a saturation in the decrease of
25   the resistivity.

It should be noted that the reflectance of the distributed Bragg reflector starts to decrease sharply with increase of thickness of the heterospike buffer layer 18c, and the reflectance is reduced to

5 the level of 99.8% or les when the thickness of the layer 18c has exceeded 50 nm. Thus, it is necessary to limit the thickness of the heterospike buffer layer 18c to be 50 nm or less in order to satisfy the requirement of high reflectance and low resistivity

10 simultaneously.

Figure 19 shows the reduction of the reflectance in detail, wherein Figure 19 shows the change rate of the reflectance R ($| dR/dt |$) with regard to the thickness t of the heterospike buffer

15 layer 18c.

Referring to Figure 19, it can be seen that there occurs a sharp rise of the reflectance when the thickness of the heterospike buffer layer has exceeded 50 nm. With this, there occurs an increase

20 of the threshold current of laser oscillation.

Thus, in the distributed Bragg reflector tuned to the wavelength of 1.3μm and having a heterospike buffer layer having a thickness of 5 nm or more but 50 nm or less, it is possible to reduce

25 the resistance caused by the heterointerface while

maintaining a high reflectance. By using such a distributed Bragg reflector in a surface-emission laser diode, it is possible to achieve a laser oscillation under a practical drive condition.

5   In the case of a surface-emission laser diode, it is necessary to design the reflector such that the distributed Bragg reflector 18 at the exit side has a relatively smaller reflectance for facilitating optical output in order to increase the

10 output power of the laser diode. Further, in order to obtain a stable laser oscillation up to the high output region (high level injection region), it is necessary to set the output saturation point as high as possible by suppressing the device heat generation.

15 The distributed Bragg reflector having a relatively thick (50nm) heterospike buffer layer 18c of the present invention satisfies these conditions and is suited for use in a high-power laser diode.

          Thus, according to the long-wavelength

20 surface-emission laser diode of the present invention, it is possible to optimize the reflectance and electric properties.of the distributed Bragg reflector used therein by optimizing the thickness of the heterospike buffer layer 18c within the range of

25 5 - 50 nm.

In the example of Figure 3, the low
refractive index layer 18a is formed of an AlAs layer
and the high-refractive index layer 18b is formed of
a GaAs layer. On the other hand, it is also possible
5   to use two AlGaAs layers for the low-refractive index
layer 18a and the high refractive index layer 18b, by
changing the Al content in the AlGaAs layers. In this
case, it is preferable to increase the difference of
the Al content between the low-refractive index layer
10   18a and the high refractive index layer 18b for
decreasing the number of stacks in the reflector, as
the reflectance of the reflector is increased with
increasing degree of difference of the refractive
index between the low refractive index layer and the
15   high refractive index layer. Thus, it will be noted
that the construction of Figure 3 provides the
maximum refractive index difference between the low
refractive index layer and the high refractive index
layer by using GaAs and AlAs.

20   As noted already, in the heteroepitaxial
structure in which there is a large difference of Al
content between the low refractive index layer and
the high refractive index layer, the band
discontinuity at the valence band is also increased
25   and there arises a problem of increased device

resistance in trade off to the increase of the
reflectance. Thus, in such a case, it is necessary to
provide the heterospike buffer layer of sufficiently
large thickness between the high refractive index
5   layer 18b and the low refractive index layer 18a for
reducing the resistivity of the reflector. However,
use of such a heterospike buffer layer has been
difficult in the conventional distributed Bragg
reflector tuned to the wavelength band of 0.85μm. In
10   the present invention, on the contrary, it is
possible to achieve a high reflectance and
simultaneously a low resistance while using the
material system of GaAs/AlAs for the distributed
Bragg reflector.

15   In the distributed Bragg reflector of
Figure 3, it is possible to form the heterospike
buffer layer 18c in the range of 20 - 50nm in the
case the reflector is tuned to the reflection
wavelength of 1.1μm or more.

20   Referring to Figure 17 again in more detail,
it can be seen that the resistivity of the
distributed Bragg reflector decreases sharply with
increase of the thickness of the heterospike buffer
layer 18c and then approaches gradually to the bulk
25   resistivity. In the example of Figure 17, the

threshold thickness of the heterospike buffer layer
18c above which the saturation of resistivity takes
place is about 20nm. At this thickness of 20nm, it
can be seen that the resistivity is reduced to about
5   twice the bulk resistivity. Thus, by using the
thickness of 20nm or more but 50nm or less, it is
possible to obtain a distributed Bragg reflector
having a resistivity comparable to the bulk
resistivity.

10   Figure 20 shows a band structure for
another distributed Bragg reflector.

             In the example of Figure 20, GaAs is used
for the high-refractive index layer 18b in the
structure of Figure 3 while the low refractive index
15   layer 18a formed of $Al_{0.8}Ga_{0.2}As$. Further, the example
of Figure 20 uses a compositional gradation layer
having a thickness of 30 nm for the heterospike
buffer layer 18c. In the example of Figure 20, the
compositional gradation layer is formed such that the
20   valence band energy changes parabolic with the
thickness. In such a parabolic compositional
gradation layer, the valence band energy has a
downwardly convex shape.

             In the construction of Figure 20, it should
25   be noted that the design wavelength (λ) of the

distributed Bragg reflector is 1.5μm, and the
thickness of the Al0.8Ga0.2As layer 18a and the
thickness of the GaAs layer 18b are respectively
chosen to 110.8nm and 125.5nm so as to be equal to λ
5   /4n, wherein n is a refractive index in the
respective layers.

In the distributed Bragg reflector of
Figure 20, each of the semiconductor layers is formed
to have a thickness subtracted with the optical
10   thickness of the parabolic compositional gradation
layer 18c from the above noted thickness. In the case
an $Al_{0.6}Ga_{0.4}As$ layer is used for the low-refractive
index layer 18a as in the case of the embodiment to
be described later, the λ/4n thickness of the
15   $Al_{0.6}Ga_{0.4}As$ layer for the distributed Bragg reflector
tuned to the 1.5μm wavelength becomes 121.7 nm.

In the present embodiment, each of the
Al0.8Ga0.2As layer 18a, the GaAs layer 18b and the
parabolic compositional gradation layer 18c is doped
20   to the p-type such that each of the foregoing layers
have a uniform carrier density of $5 \times 10^{17}cm^{-3}$.

Thus, in the present embodiment, the
resistivity of the distributed Bragg reflector is
reduced to the value generally equal to the bulk
25   resistivity in spite of the fact that the distributed

Bragg reflector is doped to a relatively small doping density of $5 \times 10^{17} cm^{-3}$ due to the use of the relatively thick compositional gradation layer 18c (50nm). The use of such a low doping density is also

5 advantageous in view of reduced optical absorption caused by the transition between the valence bands. It should be noted that, in such a distributed Bragg reflector tuned to the longer wavelength of $1.5 \mu m$, it is easy to provide a thick parabolic compositional

10 gradation layer 18c while maintaining high reflectance.

While a compositional gradation layer having a parabolic gradation is used for the heterospike buffer layer 18c in the embodiment of

15 Figure 20, the heterospike buffer layer 18c may be formed of another layer. Further, the distributed Bragg reflector may be tuned to the wavelength other than $1.5 \mu m$. Similarly, the Al composition of the low-refractive index layer may be different from the

20 one explained above. Further, the doping density may be changed in each of the layers in the distributed Bragg reflector.

As noted above, the resistance of the distributed Bragg reflector tuned to the long

25 wavelength band of $1.1 \mu m$ or more is reduced sharply

when the thickness of the heterospike buffer layer
18c is increased as is represented in Figure 17,
until the thickness of the heterospike buffer layer
18c exceeds a predetermined thickness. This

5   predetermined thickness of the heterospike buffer
layer 18c within which the sharp change of the
resistivity takes place is related to the doping
density used in the distributed Bragg reflector.

        Figure 21 shows the case the doping density

10   of 7 x 10^{17}cm-3 is used in the AlAs/GaAs distributed
Bragg reflector of Figure 20 for each of the layers
therein.

        Referring to Figure 21 in which the doping
density is reduced, it can be seen that the thickness

15   range of the heterospike buffer layer 18c in which
there occurs a sharp drop of the resistivity in the
distributed Bragg reflector has been increased to
30nm. When the foregoing limit is exceeded, it can be
seen that the resistivity is changed linearly to the

20   value of the bulk resistivity. Particularly, in the
case of a p-type distributed Bragg reflector, there
occurs an increase of optical absorption when the
hole density (doping density) is increased as a
result of optical absorption between the valence

25   bands in addition to the free carrier absorption.

Thus, when such a distributed Bragg reflector is applied to a laser diode, there is caused an increase of the laser threshold current.

Thus, from the viewpoint of optical
5   absorption, it is preferable to use a low carrier density. As the effect of the transition between the valence bands appears conspicuous for optical radiation of long wavelengths, it is important to suppress the absorption loss in the long wavelength
10 laser diode operating at the wavelength of 1.1 μm or more. In the case of a conventional distributed Bragg reflector having a doping density exceeding 1 x $10^{18}cm^{-3}$, it is difficult to reduce the absorption loss.

15   Because of this reason, there are cases in which the doping density is reduced to 1 x $10^{18}cm^{-3}$ or less in one of the low refractive index layer 18a, the high refractive index layer 18b, the heterospike buffer layer 18c, or all of the layers 18a – 18c. In
20 such a distributed Bragg reflector in which the doping density is reduced, however, there occurs an increase of extension of the depletion layer, and the problem of increase of resistance is inevitable. When the doping density is thus reduced, therefore, it is
25 necessary to increase the thickness of the

heterospike buffer layer, while it is noted that such
a compensating effect of the heterospike buffer layer
appears when the thickness thereof has reached 30 nm
or more. In the case the doping density is reduced

5   further, a more thick heterospike buffer layer 18c is
needed. In such a case, the effect of the hetero
interface is compensated for by using a larger
thickness for the heteroepitaxial buffer layer within
the foregoing range, such as 40 nm or 50 nm. A

10   similar argument applies also to the case when AlGaAs
is used in place of AlAs in the distributed Bragg
reflector.

Figure 22 shows the result of calculation
of resistivity of the distributed Bragg reflector

15   including 4 pairs of the $Al_{0.8}Ga_{0.2}As/GaAs$ structure.
In the example of Figure 22, the doping density of
each layer is reduced further to the level of 5 x
$10^{17}cm^{-3}$.

In this case, too, the heterospike buffer

20   layer 18c has a thickness of 30 nm or more and it can
be seen that the resistivity of the distributed Bragg
reflector is comparable to the resistivity of the
bulk resistivity. In the case of a distributed Bragg
reflector in which any or all of the high refractive

25   index layer 18a, low refractive index layer 18b and

the heterospike buffer layer 18c are set smaller than
the conventional doping density of $1 \times 10^{18} cm^{-3}$, for
example, there appears a saturation of resistivity
when the thickness of the heterospike buffer layer
5   18c has reached 30 nm. Thus, in the case at least one
of the layers constituting the distributed Bragg
reflector has the doping density of $1 \times 10^{18} cm^{-3}$ or
less, it is possible to decrease the resistance
effectively by using the heterospike buffer layer
10   having a thickness in the range of 30 - 50 nm.

Of course, the foregoing thickness of the
heterospike buffer layer 18c is effective also in the
distributed Bragg reflector having a larger doping
density and may be used in the case all of the layers
15   constituting the distributed Bragg reflector has a
doping density of $1 \times 10^{18} cm^{-3}$ or more. On the other
hand, it is especially advantageous to use the doping
density of $1 \times 10^{18} cm^{-3}$ or less in combination with
the heterospike buffer layer having a thickness
20   appropriately chosen from the range of 30 - 50 nm in
view of the fact that both the absorption loss and
the resistance are reduced.

By using the distributed Bragg reflector of
the embodiment of Figure 22 for the reflector in the
25   surface-emission laser diode, it is possible to

obtain a surface-emission laser diode having a superior characteristic. As noted before, it has been difficult to realize the thickness of 30 - 50 nm for the heterospike buffer layer in the conventional

5   distributed Bragg reflector tuned to the 0.85μm wavelength. The heterospike buffer layer of this thickness became possible for the first time in the distributed Bragg reflector tuned to the wavelength of 1.1μm.

10   In the distributed Bragg reflector of the present invention, it is also possible to set the difference of Al content between the low refractive index layer 18a and the high refractive index layer 18b of the distributed Bragg reflector to be less

15   than 0.8 by constituting the layers 18a and 18b by any of AlAs, GaAs and AlGaAs mixed crystal.

        When the difference of Al content between the high refractive index layer 18b and the low refractive index layer 18a is less than 0.8 in the

20   distributed Bragg reflector constituted of a semiconductor material of the AlGaAs system and tuned to the design wavelength of 1.1μm or longer, it is possible to reduce the electric resistance while maintaining a high reflectance.

25   In a mixed crystal of AlGaAs, it should be

noted that the valence band energy decreases
monotonously with the increase of Al content therein,
and the band discontinuity of the valence band at the
interface to a GaAs crystal increases with increasing

5   Al content in the AlGaAs mixed crystal. Thereby,
there is formed a large potential barrier at the
hetero interface, and this potential barrier has been
the cause of the high resistance of the distributed
Bragg reflector. Further, it should be noted that the

10   decrease of the valence band energy is generally
proportional to the Al content, and the band
discontinuity between the semiconductor layers having
different Al compositions correspond to the Al
compositional difference.

15   Figures 23 and 24 show the resistivity of
the p-type distributed Bragg reflector tuned to the
design wavelength of 1.3 μm and including 4 pairs of
high refractive index layer 18b and low refractive
index layer 18a for various thicknesses of the

20   heterospike buffer layer. In Figures 23 and 24, it
should be noted that the distributed Bragg reflector
uses GaAs for the high refractive index layer 18b and
AlAs, $Al_{0.8}Ga_{0.2}As$ and $Al_{0.6}Ga_{0.4}As$ have been used for
the low refractive index layer. Further, each of the

25   layers has been formed to have a thickness tuned to

1/4 the design wavelength while taking into consideration of the refractive index of the respective layers. Further, the doping density is set to $5 \times 10^{17} cm^{-3}$ throughout the layers in Figure 23 and

5   $1 \times 10^{18} cm^{-3}$ throughout the layers in Figure 24. It should be noted that the doping density of $1 \times 10^{18} cm^{-3}$ is used commonly in the doping of the conventional p-type distributed Bragg reflector.

From Figures 23 and 24, it can be seen that
10   the resistivity of the distributed Bragg reflector increases with increasing Al content in the AlGaAs layer and decreasing thickness of the heterospike buffer layer, and that it is necessary to provide a thick heterospike buffer layer in order to reduce the
15   resistivity of the distributed Bragg reflector to the bulk resistivity level. In the case of the distributed Bragg reflector that uses $Al_{0.6}Ga_{0.4}As$ and GaAs as the low refractive index layer 18a and the high refractive index layer 18b, for example, there
20   appears a band discontinuity of about 300meV, while the band discontinuity increases to about 400meV when $Al_{0.8}Ga_{0.2}As$ is used for the low refractive index layer 18a and GaAs is used for the high refractive index layer 18b.

25   From the results of Figures 23 and 24, it

is concluded that the thickness of 20 nm or more is

preferable for the heterospike buffer layer 18c in

order to reduce the resistivity of a distributed

Bragg reflector formed of AlAs layers and GaAs layers

5   in order to reduce the resistivity of the distributed

Bragg reflector effectively, although this would also

depend on the doping density. Thus, in the case the

band discontinuity is 400meV or less, in other words

the Al compositional difference is less than 0.8, it

10   can be seen that the resistivity of the heterospike

buffer layer can be reduced effectively by increasing

the thickness of the heterospike buffer layer to 20

nm or more.

Actually, the increase of resistance of the

15   distributed Bragg reflector caused by the band

discontinuity depends not only on the barrier height

and barrier thickness but also on the effective mass

of holes used for the carriers. However, there is no

large difference in the effective mass for heavy

20   holes between AlGaAs, AlGaInP and GaInAsP, and the

band discontinuity can be regarded as the index of

the heterointerface resistance. Thus, in the case the

valence band discontinuity is less than 400meV, and

hence the Al compositional difference is less than

25   0.8, it is possible to reduce the resistance of the

distributed Bragg reflector by using the heterospike
buffer layer having a thickness of 20nm or more.

With regard to the upper limit of the
heterospike buffer layer 18c, the thickness of the
5   heterospike buffer layer 18c should be chosen, in
view of the tuned wavelength of the distributed Bragg
reflector, such that no remarkable decrease of
reflectance occurs. By doing so, a distributed Bragg
reflector having excellent electrical and optical
10   characteristics is obtained.

In the distributed Bragg reflector having a
structure shown in Figure 3, it is possible to use
any of AlAs, GaAs and AlGaAs mixed crystal for the
low refractive index buffer layer 18a and the high
15   refractive index layer 18b such that the Al
compositional difference between the layers 18a and
18b is 0.8 or more.

In this embodiment, it is also possible to
reduce the resistance of the distributed Bragg
20   reflector effectively while maintaining a high
reflectance.

When AlAs and GaAs are combined for the low
refractive index layer 18a and the high refractive
index layer 18b, it should be noted that there
25   appears a band discontinuity of about 500meV in the

valence band, and thus, it is necessary to provide a thick heterospike buffer layer for reducing the resistivity of the distributed Bragg reflector, although the thickness of the heterospike buffer layer may depend on the doping density. In such a case, it is concluded, in view of the results of Figures 23 and 24, that the heterospike buffer layer 18c has a thickness of 30 nm or more. Thus, from the view point of band discontinuity of the semiconductor materials constituting the distributed Bragg reflector, it becomes possible to reduce the resistance of the distributed Bragg reflector by setting the thickness of the heterospike buffer layer to be 30 nm or more in the case there exists a band discontinuity is 400meV or more.

Thus, there holds a relationship explained with reference to Figures 23 and 24 between the Al compositional difference and the valence band discontinuity, and the valence band discontinuity of 400meV corresponds to the Al compositional difference of 0.8 or more. Thus, in the case the Al compositional difference is 0.8 or more, the thickness of 30nm or more is needed for the heterospike buffer layer 18c so as to reduce the resistance effectively. By providing such a

heterospike buffer layer as such, it is possible to reduce the resistance of the distributed Bragg reflector effectively.

With regard to the upper limit of the
5   heterospike buffer layer, the thickness of the heterospike buffer layer 18c is chosen in view of the tuned wavelength of the distributed Bragg reflector such that there occurs little decrease of reflectance. Thereby, it becomes possible to realize a distributed
10 Bragg reflector having excellent characteristics both in terms of electric properties and optical properties.

In the distributed Bragg reflector of the present invention tuned to the design wavelength of
15 1.1μm, it is also possible to set the thickness of the heterospike buffer layer 18c with respect to the tuned wavelength λ [nm] to be equal to or smaller than $(50\lambda-15)$ [nm]. In such a case, too, it is possible to reduce the resistance of the distributed
20 Bragg reflector while maintaining high reflectance. Figure 25 shows the relationship between the thickness of the heterospike buffer layer and reflectance of the distributed Bragg reflector tuned to the wavelength of $1.1 - 1.7\mu$m. It should be noted
25 that the distributed Bragg reflector has a structure

explained with reference to Figure 3 and uses GaAs for the high refractive index layer 18b and AlAs for the low refractive index layer 18a. The layers 18a and 18b are repeated with the number determined such

5 that the reflectance exceeds 99.9% at each of the tuned wavelengths. Thus, in the case of the reflector is tuned to 0.88μm, the layers 18a and 18b are repeated 18 times, while in the case of the reflector is tuned to 1.1μm, the layers 18a and 18b are

10 repeated 22 times. Further, in the case the reflector is tuned 1.3 micron, the layers 18a and 18b are repeated 23 times while in the case the reflector is tuned to 1.5μm, the layers 18a and 18b are repeated 23 times. Further, in the case the reflector is tuned

15 to 1.7μm, the layers 18a and 18b are tuned to 24 times.

Figure 26 shows a change rate of the resistivity of the distributed Bragg reflector shown in Figure 25 ($| dR/dt |$) with the thickness of the

20 heterospike buffer layer.

From Figure 25, it can be seen that reflectance of the reflector decreases with increasing thickness of the heterospike buffer layer. Further, Figure 26 shows that the decrease of the

25 reflectance increases suddenly at a certain thickness

of the heterospike buffer layer. For the sake of
facilitating understanding of this situation, Figure
26 shows lines drawn as a tangential for each of the
curves as the reference reflectance change rate. For
5   example, in the distributed Bragg reflector tuned to
1.3 μm, it can be seen from Figure 26 that the change
rate of the reflectance increases sharply when the
thickness of the heterospike buffer layer 18c has
exceeded 50nm. In correspondence thereto, there
10 occurs a sharp drop in the reflectance of the
distributed Bragg reflector. Thus, in the surface-
emission laser diode having such a distributed Bragg
reflector for the reflector, the threshold current of
laser oscillation increases sharply at the foregoing
15 thickness of the heterospike buffer layer 18c.
Further, it should be noted that the thickness of the
heterospike buffer layer 18c corresponding to such a
sharp change of reflectance changes depending on the
design wavelength of the laser diode. Thus, longer
20 the design wavelength of the laser diode, the
thickness of the semiconductor layers constituting
the reflector is increased, and the effect of the
heterospike buffer layer is reduced.

    Thus, the thickness of the heterospike
25 buffer layer corresponding to such a sudden increase

of change rate of the reflectance changed depending
on the design wavelength, while the threshold of the
change rate corresponding to the onset of the sudden
growth does not change with the design wavelength and
5   maintains the value of about 0.9 as can be seen from
Figure 26.

Table 2 below summarizes the threshold
thickness for each wavelength shown in Figure 25.

10

Table 2

design wavelength	1.1μm	1.3μm	1.5μm	1.7μm
threshold thickness	40nm	50nm	60nm	70nm

From Table 2, it can be seen that the
design wavelength and the threshold thickness are in
a generally linear relationship and there holds a
15   relationship between the threshold thickness t [nm]
and the design wavelength λ [nm] of the distributed
Bragg reflector as follows:

$$t = 50\lambda - 15. \qquad (1)$$

Thus, by providing the heterospike buffer
20   layer 18c in the distributed Bragg reflector tuned to
the wavelength of 1.1μm or more with the thickness
not exceeding the thickness t given by Equation (1),
it is possible to realize a low-resistance

distributed Bragg reflector having a high reflectance.

In the example above, it was assumed that the heterospike buffer layer has a linear compositional graduation profile. However, it is also

5 possible to use non-linear profile. In this case, too, similar results and effects are achieved.

In the present invention, it is possible to increase the thickness of the heterospike buffer layer to be 20nm or more in the distributed Bragg

10 reflector having a thickness of 1.1μm. In this case, too, it is possible to reduce the resistance of the mirror while maintaining a high reflectance.

As explained before, there holds a relationship of Equation (1) between the thickness of

15 the heterospike buffer layer and the design wavelength of the distributed Bragg reflector that can maintain a high reflectance.

With regard to the electric properties of the distributed Bragg reflector, it is possible to

20 reduce the effect of the hetero interface by increasing the thickness of the heterospike buffer layer as noted before, and a distributed Bragg reflector having a reduced resistance is obtained. Further, the effect of the resistance reduction by

25 the heterospike buffer layer id determined by the

materials used for the distributed Bragg reflector and the doping density and further by the compositional profile. Essentially, it does not depend on the reflection wavelength. Thus, it is concluded that there exists a lower limit in the thickness of the heterospike buffer layer in which the resistance of the distributed Bragg reflector is decreased sufficiently. In order to provide a distributed Bragg reflector having a sufficiently low resistance, it is necessary to provide the heterospike buffer layer with a thickness exceeding a predetermined thickness.

In the example of the distributed Bragg reflector of Figure 24 in which the semiconductor layers are doped uniformly to the doping density of 1 x 10^{18}cm^{-3}, it can be seen that the resistivity of the distributed Bragg reflector increases in terms of orders when the thickness of the distributed Bragg reflector is les than 20nm. When the thickness of the heterospike buffer layer has exceeded the value of 20nm, on the other hand, it is preferable to use the thickness of 20nm or more for the heterospike buffer layer, provided that the semiconductor layers constituting the distributed Bragg reflector has the foregoing doing density.

From the description noted above, it is concludes that a distributed Bragg reflector having a sufficiently low resistance and simultaneously maintaining a high optical reflectance is obtained by

5 choosing the thickness t [nm] of the heterospike buffer layer with regard to the design wavelength λ of the distributed Bragg reflector so as to satisfy the relationship $20 \leqq t \leqq 50 \lambda - 15$.

In the distributed Bragg reflector of this

10 embodiment, it is also possible to set the thickness of the heterospike buffer layer to be 30nm or more. Even in such a case, it is possible to decrease the resistance of the reflector effectively while maintaining a high reflectance at the tuned

15 wavelength or design wavelength of 1μm or longer.

In semiconductor materials, there is a tendency that optical absorption increases also for the photons having energy smaller than the bandgap with increase of free carriers. Further, in the case

20 of the p-type semiconductor materials, there arises conspicuous optical absorption caused as a result of the valence band to valence band absorption with the increase holes acting as the carriers. As the problem of the valence band to valence band absorption

25 becomes conspicuous with increasing optical

wavelength, this problem becomes a serious problem in the distributed Bragg reflector having a long wavelength of 1.1μm or more. It should be noted that such optical absorption becomes the cause of

5   decreasing the reflectance of the distributed Bragg reflector. In the case of the laser diode using such a reflector, there arises a problem of increase of threshold current caused by optical absorption and decrease of efficiency. Thus, from the view point of

10   decreasing the optical absorption, it is preferable that the doping density of the semiconductor layers is set as small as possible. However, with the decrease of the doping density, there arises a problem of increase of thickness of the

15   heterointerface, and the effect of the interface potential is increased, thus leasing to the problem of increase of resistance of the distributed Bragg reflector.

     Thus, in the case of the semiconductor

20   distributed Bragg reflector having the reduced doping density, it is necessary to use a thicker heterospike buffer layer for reducing the resistivity. In the case of doping the semiconductor layers constituting the distributed Bragg reflector to the doping density

25   of 5 x 10^{17}cm^{-3}, it can be seen from Figure 23 that

the resistivity is reduced to the level of the bulk

material when the thickness of the heterospike buffer

layer is increased to 30nm or more.

With regard to the doping density and

5   profile, there are numerous combinations, while there

arises a similar tendency when the doping density of

one of the semiconductor layers is less than 1 x

$10^{18}cm^{-3}$. This is because the potential barrier formed

at the hetero interface has the height and thickness

10   depending on the doping density of the semiconductor

layer adjacent to the hetero interface. Lower the

doping density, as in the case of the doping density

having a value of 1 x $10^{18}cm^{-3}$, larger the influence

of the hetero interface. Further, the electric

15   property of the distributed Bragg reflector is mainly

determined by the hetero interface where the doping

density is small. Thus, the present invention is

effective also in the case in which at least one of

the semiconductor layers constituting the distributed

20   Bragg reflector has a doping density of less than 1 x

$10^{18}cm^{-3}$.

It should be noted that a similar tendency

appears also in the case of the distributed Bragg

reflector doped to the order of 1 x $10^{17}cm^{-3}$. Of

25   course, it is possible to reduce the doping density

further, provided that the thickness of the heterospike buffer layer is increased to 30nm or more within the upper limit noted before.

Thus, according to the present embodiment,

5 it is possible to obtain a distributed Bragg reflector having a sufficiently low resistance and high optical reflectance by choosing the thickness t [nm] of the heterospike buffer layer with regard to the design wavelength λ of the laser diode so as to

10 fall in the range of $30 \leqq t \leqq 50\lambda - 15$.

In the conventional laser diode operable at the wavelength band of 0.85μm, there has been a study to provide a heterospike buffer layer as noted above. On the other hand, such a heterospike buffer

15 layer is most effectively used in the long-wavelength surface-emission laser diode operable at the wavelength of $1.1 - 1.7 \mu$m. In the $1.1 - 1.7 \mu$m band, for example, it is possible to set the thickness of the material layer constituting the heterospike

20 buffer layer about twice the thickness for the case of the 0.85μm band, in order to obtain the same reflectance (99.5% or more, for example). Thereby, the resistance of the semiconductor Bragg reflector is reduced, and the operational voltage, oscillation

25 threshold current, and the like, are likewise reduced.

Thereby, advantageous features such as suppression of heating, stable laser oscillation and low energy drive is obtained for the laser diode.

Thus, the provision of such a heterospike
5 buffer layer to the semiconductor Bragg reflector according to the present invention is deemed an advantageous improvement especially in the case of the long-wavelength surface-emission laser diode operable in the laser oscillation wavelength of 1.1 –
10 1.7 μm.

For example, in the case of the surface-emission laser diode operable at the wavelength band of 1.3 μm and having a semiconductor Bragg reflector in which a low refractive index layer of $Al_xGa_{1-x}As$
15 (x=1.0) and a high refractive index layer of $Al_yGa_{1-y}As$ (y=0) are stacked for 20 periods, a reflectance of 99.7% or less is obtained, provided that the thickness of the heterospike buffer layer $Al_zGa_{1-z}As$ ($0 \leqq y < z < x \leqq 1$) is set to 30nm. Further, a reflectance
20 of 99.5% or more is obtained when the heterospike buffer layer has a thickness of 53nm. Thus, a film thickness control of ± 2% is sufficient when the distributed Bragg reflector is designed to have a reflectance of 99.5% or more. In the experiments,
25 distributed Bragg reflectors were produced with the

thickness of 10nm, 20nm and 30nm for the heterospike buffer layer. It turned out that a reflectance sufficient for practical use was achieved in any of these experiments. In this way, a 1.3 μm band

5   surface-emission laser diode having a reduced resistance for the semiconductor Bragg reflector was realized and laser oscillation was achieved. The remaining structural feature of the laser diode thus produced will be explained later.

10   In a multilayer reflector, there exists a band of high reflectance in the designed wavelength band (assuming that complete film thickness control is achieved). This is called high reflectance band, wherein the high reflection band may include also the

15   wavelength band in which a reflectance exceeding a target value is achieved for a target wavelength. In the high reflectance band, the reflectance becomes largest at the designed wavelength, while the reflectance falls off but only slightly as the

20   deviates from the designed wavelength. When the deviation exceeds a certain limit, the reflectance falls off sharply.

           Thus, in a multilayer reflector, it is necessary to control the thickness of the multilayer

25   reflector completely with atomic layer level so that

a reflectance exceeding the necessary reflectance is
that achieved at the target wavelength. In practice,
a deviation of about ±1% is inevitable for the film
thickness, and thus, it is a common place that the

5   target wavelength and the wavelength in which the
reflectance is maximized are different. In the case
the target wavelength is 1.3μm, for example, the
wavelength providing the maximum reflectance is
deviated by 13nm when there is an error of ±1% in

10   the film thickness control. Therefore, it is
desirable that this high reflectance band has a wide
bandwidth. Here the high reflectance band is defined
as the wavelength band in which a reflectance
exceeding a necessary reflectance is obtained for a

15   target wavelength.

Thus, in the long-wavelength surface-
emission laser diode oscillating at the wavelength of
$1.1 - 1.7\mu$m, it is possible to reduce the resistance
value of the semiconductor Bragg reflector while

20   maintaining high reflectance, by optimizing the
constitution of the reflector. Thereby, the operating
voltage, oscillation threshold current, and the like,
of the laser diode are successfully reduced, and heat
generation is suppressed effectively. As a result,

25   stable laser oscillation is realized and low energy

driving of the laser diode becomes possible.

Once again Figure 1 is referred to.

It can be seen that a p-type GaAs layer 19 having a composition represented as $Al_xGa_{1-x}As$ (x=0)

5 is provided on the upper semiconductor Bragg reflector 18 as a contact layer (p-contact layer), so as to achieve a contact with the p-side electrode 20.

In the constitution of Figure 1, it should be noted that the In content x of the quantum well

10 active layer is set to 39% (Ga 0.61In0.39As). Further, the thickness of the quantum well active layer is set to 7nm. The quantum well active layer thus formed accumulates a compressional strain of about 2.8% with respect to the GaAs substrate.

15 In the surface-emission laser diode of Figure 1, the deposition of the semiconductor layers is conducted by an MOCVD process. In this case, no lattice-relaxation phenomenon was observed. Each of the semiconductor layers of the laser diode may be

20 formed by using TMA (trimethyl aluminum), TMG (trimethyl gallium), TMI (trimethyl indium), AsH_3 (arsine), PH_3 (phosphine) as source materials, together with a carrier gas of H_2. In the case of growing the active layer (the quantum well active

25 layer) in the form of highly strained layer as in the

case of the device of Figure 1, it is preferable to use a low temperature growth process that realizes a non-equilibrium growth. In the present case, the GaInAs layer 15a (quantum well active layer) is grown

5   at 550℃. It should be noted that the MOCVD process used herein is characterized by high degree of supersaturation and is suited for the crystal growth of highly strained active layer. Further, the MOCVD process does not require high vacuum environment as

10 in the case of MBE process. Further, the MOCVD process is suitable for mass production, as the process control is achieved by merely controlling the supply rate or supply duration of the source gases.

In the illustrated laser diode, there is

15 formed a high resistance region 15F outside the current path by means of ion implantation of protons (H+) as a current confinement structure.

In the constitution of Figure 1, it should be noted that there is formed a p-side electrode 20

20 on the p-type contact layer formed in turn on the uppermost part of upper part reflector 18 and constituting a part thereof, except for an optical exit part 20A. Also there is formed an n-side electrode 21 at the rear surface of the substrate.

25 In the present embodiment, it should be

noted that the active region including the upper part and lower part spacer layers 14 and 16 in addition to the multiple quantum well active layer 15 and forming the resonator between the upper and lower reflectors

5   12 and 18, in which the career recombination is caused upon injection of carriers, is formed of a material not containing Al (the proportion to the group III element(s) is 1% or more). Furthermore the low refractive index layers constituting the lower

10   part reflector 12 and also the upper part reflector 18 closest to the active layer is formed of the non-optical recombination elimination layers 13 and 17 each having a composition of $Ga_xIn_{1-x}P_yAs_{1-y}$ ($0<x\leqq 1, 0<y\leqq 1$), in which the compositional parameters x

15   and y are chosen appropriately. More specifically, GaInP or GaInPAs or GaPAs is used for the non-optical recombination elimination layer. The material constituting the non-optical recombination elimination layer thus has a composition of $Ga_xIn_{1-x}P_yAs_{1-y}$

20   $Ga_xIn_{1-x}P_yAs_{1-y}$ ($0<x\leqq 1, 0<y\leqq 1$), wherein the non-optical recombination layer may be added further with a trace amount of element(s) other than Al.

In such a structure, the careers are confined between the low refractive index layer of

25   the upper part reflector and the low refractive index

layer of the lower part reflector that are located
nearest to the active layer and formed of a wide gap
material. In such a structure, there occurs non-
optical recombination of carriers even when the
5   active region is formed of the layer not containing
Al (the proportion of Al with regard to group III
elements is 1% or less) upon injection of the careers,
as there occurs non-optical recombination of carriers
at the interface between the active layer and the low
10   refractive index layer of the upper or lower
reflector, as long as the foregoing low refractive
index layer (wide gap layer) contains Al. When the
non-optical recombination of carriers takes place,
the efficiency of optical emission is deteriorated.
15   Therefore it is desirable to form not only the active
region but also the low refractive index layers
adjoining thereto by a material not containing Al.

Further, the non-optical recombination
elimination layer having the primary composition of
20   GaxIn1-xPyAs1-y (0<x$\leqq$1,0<y$\leqq$1) has a lattice
constant smaller than the lattice constant of the
GaAs substrate. Thus, the layer accumulates a tensile
strain.

In an epitaxial growth process, the growth
25   is made while reflecting the information of the

foundation layer on which the growth is made. Thus, when there are defects on surface of the foundation layer, the same defects crawl up to the growth layer. On the other hand, it is known that such a crawling

5 up of the defects can be suppressed by interposing a strained layer on the path of the defects.

In the case an active layer accumulates therein a strain, there sometimes occurs a problem in that growth of the active layer with desired

10 thickness is difficult because of the reduced critical thickness. Particularly, there arises a problem in that the film growth does not take place at all even if a low temperature growth process or non-equilibrium growth process is employed, due to

15 the existence of defects. This problem occurs particularly when the active layer accumulates a compressive strain of 2% or more, or when growing the active layer beyond the critical thickness thereof.

On the other hand, when there exists a

20 strained layer adjacent to the active layer, such a crawling up of the defects is intercepted and the efficiency of optical emission is improved. Further, it becomes possible to grow the active layer even in the case the active layer accumulates a compressive

25 strain of 2% or more. Further, it is possible to grow

the strained layer beyond the critical thickness.

It should be noted that the GaxIn1-xPyAs1-y (0<x≦1,0<y≦1) layers 13 and 17 adjoin the active region and function so as to confine the careers into
5   the active region. On the other hand, the GaxIn1-xPyAs1-y (0<x≦1,0<y≦1) layers 13 and 17 also have the feature in that the bandgap energy can be increased by decreasing the lattice constant. In the case of GaxIn1-xP (y=1), for example, there occurs an
10 increase of the lattice constant when the compositional parameter x has increased and the film composition has approached the composition GaP. Associated therewith, there occurs an increase of bandgap. It should be noted that the bandgap energy
15 Eg is given as Eg (Γ)=1.351+0.643x+0.786x^2 in the case of direct transition and Eg (X)=2.24+0.02x in the case of indirect transition. Therefore, the hetero barrier height between the active region and the GaxIn1-xPyAs1-y (0<x≦1,0<y≦1) layer 13 or 17 is
20 increased and the degree of career confinement is improved. Thereby, the threshold current is reduced and the temperature characteristics are improved.

Furthermore, it should be noted that the non-optical recombination elimination layer 13 or 17
25 having the composition GaxIn1-xPyAs1-y (0<x≦1,0<y≦

1) has a lattice constant larger than the lattice
constant of the GaAs substrate. Also the lattice
constant of the active layer is larger than the
lattice constant of the $Ga_xIn_{1-x}P_yAs_{1-y}$ $(0<x\leqq1,0<y\leqq$
5   1) layer 13 or 17. Thus, these layers accumulate
compressional strain therein. As the direction of the
strain accumulated in the $Ga_xIn_{1-x}P_yAs_{1-y}$ $(0<x\leqq1,0<y$
$\leqq1)$ layer is the same as the direction of the strain
accumulated in the active layer, the substantial
10   amount of the compressional strain that the active
layer senses is reduced. Larger the strain, the
influence of external factor is also large. Thus, the
construction of the present invention is especially
effective in the case that the active layer
15   accumulates a large compressional strain of 2% or
more, or the critical film thickness has been
exceeded.

It is preferable to form a surface-emission
laser diode of the 1.3 μm band on a GaAs substrate.
20   Further, there are many cases in which a
semiconductor multilayer reflector is used for the
resonator. In such a case, it is necessary to grow 50
to 80 semiconductor layers with a total thickness of
5 - 8 μm. (In the case of an edge-emission type laser
25   diode, on the other hand, the total thickness before

growth of the active layer is about 2 μm, and itg is sufficient to grow just about three layers.)

Thus, even if a high quality GaAs substrate is used, increase of defect density of the surface on
5 which the growth of the active layer is made, in the sate immediately before the growth of the active layer growth is inevitable. Once formed, the defects thus formed crawl up in the direction of the crystal growth. Further, there may be additional defect
10 formation at the hetero surface. On the other hand, measures such as provision of strain layer before the growth of the active layer or reduction of the substantial strain which the active layer senses, are effective for reducing the influence of the defects
15 on the surface on which the growth of the active layer is made in the state immediately before the growth of the active layer.

In this embodiment, Al is expelled from the active layer and further from the interface region
20 between the active region and the reflector. Thus, the problem of non-optical recombination of carriers originating from the crystal defects and caused by Al at the time of career injection is successfully removed.

25 As noted before, while it is preferable to

provide the non-optical recombination elimination
layer not containing Al at the interface of both of
the reflectors 12 and 18, beneficial effect can be
obtained also in the case the non-optical

5 recombination elimination layer is provided to only
one of the reflectors. In the illustrated example,
both of the upper and lower reflectors 12 and 18 are
formed of the semiconductor Bragg reflector. However,
it is possible to form one of the reflectors by the

10 semiconductor Bragg reflector and form the other
reflector by a multilayer dielectric reflector.

In the foregoing example, only the low
refractive index layer closet to the active layer
forms the GaxIn1-xPyAs1-y (0<x$\leqq$1,0<y$\leqq$1) non-optical

15 recombination elimination layer 13 or 17 in any of
the reflectors 12 and 18. However, it is possible to
form the non-optical recombination elimination layer
13 or 17 by a plurality of GaxIn1-xPyAs1-y (0<x$\leqq$
1,0<y$\leqq$1) layers.

20 In this embodiment, the above concept is
applied particularly to the lower reflector 12
located between the GaAs substrate and the active
layer, and the problem of crawling up of crystal
defects originating from Al at the time of the growth

25 of the active layer and the adversary influence

thereof, are suppressed successfully. As a result, the active layer can be grown with high quality, and a highly reliable surface-emission laser diode oscillating with high efficiency and sufficient for

5   practical use is obtained. In the present embodiment, the Al-free, GaxIn1-xPyAs1-y (0<x≦1,0<y≦1) layer is used only for the low refractive index layer located closest to the active region in the semiconductor Bragg reflector. Therefore, it is possible to achieve

10   the foregoing effect without increasing the number of stacks of the reflector.

The surface-emission laser diode thus produced oscillated successfully at the wavelength of about 1.2μm. While the wavelength of GaInAs formed

15   on a GaAs substrate increases with increase of In content therein, such an increase of the In content is accompanied with an increase of strain. Thus, it has been thought that the wavelength of 1.1μm would be the limit of the increase of laser oscillation

20   wavelength in the laser diode that uses GaInAs. See IEEE Photonics. Technol. Lett. Vol.9 (1997) pp.1319-1321.

In the present invention, the inventor could successfully achieve the laser oscillation at

25   1.2μm by using highly non-equilibrium growth

processes conducted at low temperature of 600°C or
less. By using such a process, it became possible to
achieve a coherent growth of the highly strained
GaInAs quantum well active layer with large thickness
5 not possible before. Meanwhile, this wavelength is
transparent with respect to a Si semiconductor
substrate. Thus, the laser diode of the present
invention can be used to construct a circuit chip
that uses optical transmission through the Si
10 substrate, by integrating an electronic device and an
optical device commonly on a Si substrate.

From the explanation noted above, it was
discovered that a long-wavelength surface emission
laser diode can be constructed successfully on a GaAs
15 substrate by using a highly strained GaInAs layer
containing a large amount of In and hence a large
amount of compressive strain for the active layer.

As noted before, such a surface-emission
laser diode can be formed by using an MOCVD process.
20 However, it is also possible to use an MBE process or
other growth process for this purpose. In the
embodiment described heretofore, a triple quantum
well structure (TQW) was used for the active layer.
However, it is also possible to use a structure
25 having different number of quantum well layers (SQW,

MQW).

  Further, it should be noted that the laser diode may also have a different structure. Further, the resonator length is not limited to λ but may have

5 a length of integer multiple of $\lambda/2$ or preferably λ.

  In the embodiment described heretofore, the laser diode was constructed on the GaAs substrate. However, it is also possible to use an InP substrate. Further, the period of repetition of in the

10 reflectors may be changed.

  In the embodiment described heretofore, the active layer of GaxIn1-xAs (GaInAs active layer) containing Ga, In and As as the major element is used in this example. On the other hand, it is possible to

15 add N to the active layer of the laser diode. In this case, the active layer contains Ga, In, N and As as major elements (GaInNAs active layer), and the laser diode can oscillate at further longer wavelengths.

  By changing the composition of the GaInNAs

20 active layer, it is possible to achieve laser oscillation at any of the 1.3 μm band and 1.55 μm band. By choosing the composition of the active layer appropriately, it is also possible to realize a surface-emission laser diode laser oscillating at

25 further longer wavelengths such as 1.7 μm.

It is also construct a surface-emission
laser diode operable at the wavelength of 1.3 μm
band on a GaAs substrate by using GaAsSb for the
active layer.

5   Conventionally, there has been no material
suitable for realizing a laser diode operable at the
wavelength of 1.1 - 1.7μm. By using a highly
strained layer of GaInAs, GaInNAs or GaAsSb for the
active layer, and by using a non-optical

10   recombination elimination layer, the present
invention successfully realized a highly efficient
surface-emission laser diode operable in the long
wavelength region of a/the 1.1 - 1.7μm band.

15   [Second embodiment]

Next, the constitution of another long-
wavelength surface-emission laser diode applicable to
an optical transmission/reception system of this
invention as a light-emitting device that is will be

20   described by using Figure 27. In the drawing, those
parts corresponding to the parts described previously
are designated by the same reference numerals and the
description thereof will be omitted.

Figure 27 is referred to.

25   Similarly to the previous embodiment of

Figure 1, this embodiment also uses an n-type GaAs substrate 11 having a surface orientation of (100).

On the GaAs substrate 11, it can be seen that the n-type semiconductor Bragg reflector (Al

5 $_{0.9}$Ga$_{0.1}$As/GaAs lower part reflectors) 12 is formed by alternately depositing the n-type AlGaAs having a composition of AlxGa1-xAs (x=0.9) and an n-type GaAs having a composition of AlxGa1-xAs (x=0) alternately for 35 periods, each with a thickness of 1/4 times

10 the oscillation wavelength λ in each medium (thickness of λ/4). Further, the n-type InGaP layer 13 is formed on the lower Bragg reflector 12 with a composition of GaxIn1-xPyAs1-y (x=0.5, y=1) and a thickness of λ/4. Thereby, the n-type GaxIn1-xPyAs1-

15 y (x=0.5, y=1) layer 13 forms one of the low refractive index layers constituting a part of the lower part reflector 12.

On the InGaP layer 13, the multiple quantum well active layer 15 is formed by stacking the

20 undoped lower GaAs spacer layer 14 and further the GaxIn1-xNyAs1-y quantum well active layer 15a three times on the spacer layer 14, with the GaAs barrier layer 15b of 15nm thickness interposed therebetween to form a triple quantum wells (TQW) structure.

25 Further, the undoped upper GaAs spacer layer 16 is

formed on the multiple quantum well active layer 15 thus formed, wherein the lower spacer layer 14, the multiple quantum well active layer 15 and the upper GaAs spacer layer 16 constitute together a resonator

5   15R having a thickness of one wavelength (λ) of the oscillation wavelength in the medium. The resonator 15R constitutes the active region of the surface-emission laser diode.

Further, the p-type semiconductor Bragg

10   reflector (the upper part reflector) 18 is formed on the resonator 15R.

It should be noted that the upper part reflector 18 includes a low refractive index layer having a thickness of $3\lambda/4$ formed of an AlAs layer

15   18_1 used for a selective oxidizing layer, wherein the foregoing low refractive index layer is sandwiched by the GaInP layer 17 and an AlGaAs layer. The GaInP layer 17 is doped with C has a composition represented as $Ga_xIn_{1-x}P_yAs_{1-y}$ (x=0.5, y=1), wherein

20   the GaInP layer 17 is formed to have a thickness of $\lambda/4-15nm$. On the other hand, the AlAs layer constituting the selective oxidizing layer is doped with C and has a composition represented as $Al_zGa_{1-z}As$ (z=1) and a thickness of 30nm. Further, the

25   foregoing AlGaAs layer is a C-doped AlGaAs layer

having a composition represented by AlxGa1-xAs
(x=0.9) and a thickness of $2\lambda/4$-15nm.

On the foregoing low refractive index layer,
a GaAs layer having a thickness of $\lambda/4$ is formed for
5   one period, and a p-type AlGaAs layer, doped with C
and having a composition of expressed with AlxGa1-xAs
(x=0.9) and a p-type GaAs layer doped with C and
having a composition represented by AlxGa1-xAs (x=0),
are stacked 22 periods each with a thickness of 1/4
10   times the laser oscillation wavelength in each medium.
Thereby a periodic stack structure constituting the
essential part of the upper part reflector 18 is
formed.

In this embodiment, too, the heterospike
15   buffer layer 18c of intermediate refractive index is
provided in the semiconductor Bragg reflector 18 by
an AlzGa1-zAs ($0\leqq y<z<x\leqq1$) layer between the low
refractive index layer 18a and the high refractive
index layer 18b as already explained with reference
20   to Figure 2. In Figure 27, illustration of the
heterospike buffer layer 18c will be omitted for the
sake of simplicity.

In this embodiment, the p-type GaAs layer
having the composition of AlxGa1-xAs (x=0) and
25   constituting the uppermost part of the semiconductor

Bragg reflector 18 functions as a contact layer (p-contact layer) that secures electrical contact to the electrode.

In the surface-emission laser diode of this
5   embodiment, the In content x of the quantum well
active layer 15a is set to 37% and the N (nitrogen)
content is set to 0.5%. The thickness of the quantum
well active layer 15a is set to 7nm.

In this embodiment, the growth of the
10 semiconductor layers constituting the said surface-
emission laser diode was conducting by using an MOCVD
process. More specifically, TMA (trimethyl aluminum),
TMG (trimethyl gallium), TMI (trimethyl indium), AsH3
(arsine) and PH3 (phosphine) are used respectively as
15 the source materials of Al, Ga, In, As and P. Further,
DMHy (dimethyl hydrazine) was used as the source
material of nitrogen. DMHy decomposes at a low
temperature and is suited for a low temperature
growth process conducted at 600°C or less.
20 Particularly, it is suited to grow a quantum well
layer of large strain, which needs a low temperature
growth process. In the MOCVD process, H_2 is used for
the carrier gas. Further, the growth of the GaInNAs
layer (quantum well active layer) was conducted at
25 540°C.

It should be noted that MOCVD process is characterized by large degree of supersaturation and is suited for the crystal growth of a material that contains N and simultaneously other group V elements.

5 Further, the MOCVD process does not require the high vacuum environment, contrary to the MBE process. Further, it is suitable for mass production, as it is only sufficient to control the supply rate and supply time of the source gases.

10 In this embodiment, a predetermined part of the stacked structure thus formed is etched until it reaches the p-type $Ga_xIn_{1-x}P_yAs_{1-y}$ (x=0.5, y=1) layer 17. Thereby, there is formed a mesa structure that exposes the $p-Al_zGa_{1-z}As$ (z=1) selective oxidizing

15 layer 18$_1$ at the sidewall thereof. Furthermore, said $Al_zGa_{1-z}As$ (z=1) layer 18$_1$ thus exposed is oxidized from the mesa sidewall by water vapor, and there is formed a current confinement layer 18$_2$ having a composition represented as Al_xO_y.

20 Finally, the part removed with the mesa etching process previously is filled by polyimide to form a planarized structure, and the polyimide film covering the upper part reflector is removed. With this, there is formed a polyimide region 18$_3$.

25 Furthermore the p-side electrode 20 is formed on the

p-type contact layer except for the optical exit part,
and an n-side electrode 21 is formed on the rear side
of the GaAs substrate 11.

In this embodiment, the GaxIn1-xPyAs1-y
5 (0<x≦1,0<y≦1) layer 17 is inserted below the
selective oxidizing layer 18₁ as a part of the upper
part reflector 18. In the case a wet etching process
by using a sulfuric acid etchant is employed in the
formation of the mesa structure, the etching stops
10 spontaneously at the GaxIn1-xPyAs1-y (0<x≦1,0<y≦1)
layer 17, as a material of the GaInPAs system
functions as an etching stopper layer to the etching
process of a material of the AlGaAs system. Thus, by
using a wet etching process by a sulfuric etchant for
15 the formation of the mesa structure, it is possible
to control the height of the mesa structure
rigorously.

Because of this, the homogeneity and
reproducibility are improved substantially for the
20 surface-emission laser diodes that are formed
simultaneously on a substrate and the production cost
is reduced. This feature is particularly advantageous
when producing a laser diode array in which a number
of surface-emission laser diodes are integrated in
25 one-dimensional or two-dimensional array.

In the embodiment of Figure 27, it is noted
that the $Ga_xIn_{1-x}P_yAs_{1-y}$ $(0<x\leq 1, 0<y\leq 1)$ layer 17
that acts also as an etching stopper layer is
provided on the side of upper part reflector 18.
5   Further, a similar GaInP layer 13 is provided on the
lower part reflector 12.

In this embodiment, too, the active region
15 sandwiched between the upper and lower reflectors
12 and 18 and cause recombination upon injection of
10   carriers is formed of a material free from Al.
Further, the low refractive index layer of the lower
and upper reflectors 12 and 18 closest to the active
layer 15 is formed of the non-optical recombination
elimination layer 13 or 17 having a composition
15   represented by $Ga_xIn_{1-x}P_yAs_{1-y}$ $(0<x\leq 1, 0<y\leq 1)$. Thus,
Al is not contained at the interface between the
active region 15 and the reflector 12 or 18, and the
problem of non-optical recombination caused by the
crystal defects, which in turn are caused by Al, is
20   effectively eliminated.

While such a construction of using an Al-
free material at the interface between the reflector
and the active region is preferably provided to both
of the upper and lower reflectors 12 and 18, the
25   advantageous effect of the present invention is

obtained also in the case such a construction is used on only one of the upper and lower reflectors 18 and 12. Further, it is also possible to use a semiconductor Bragg reflector in only one of the

5   reflectors and form the other reflector by a dielectric reflector.

As the lower part reflector 12 provided between the GaAs substrate 11 and the active layer 15 is constructed similarly to the case of Figure 1 in

10   the present embodiment, the adversary effects of crawling up of the crystal defects, originating from Al, into the active layer is effectively suppressed. Thereby, the active layer 15 can be formed with high quality.

15   It should be noted that such a non-optical recombination elimination layer 13 or 17 constitutes a part of the semiconductor Bragg reflector 12 or 18 in any of the constitution of Figure 1 or 27, and thus, the thickness thereof is set to 1/4 the

20   oscillation wavelength λ as measured in the medium (λ/4). It is also possible to provide such a non-optical recombination elimination layer in plural numbers.

In the example above, the non-optical

25   recombination elimination layer 13 or 17 is provided

to a part of the semiconductor Bragg reflector 12 or
18. On the other hand, it is also possible to provide
such a non-optical recombination elimination layer
inside the resonator 15. In the case the resonator 15
5   is formed of the active layer 15 consisting of the
GaInNAs quantum well layer 15a and the GaAs barrier
layer 15b, for example, it is possible to use the
GaAs layer as the first barrier layer and the non-
optical recombination elimination layer of GaInPAs,
10 GaAsP or GaInP as the second barrier layer. Thereby,
it is possible to set the thickness of the resonator
to one wavelength. In this case, because of the large
bandgap of the non-optical recombination elimination
layer as compared with the first GaAs barrier layer,
15 the active region in which carrier injection takes
place is substantially limited up to the region of
the GaAs barrier layer.

In the case that the process of removing
the residual Al source material or Al reactant, Al
20 compound or Al during the fabrication process of the
laser diode, it is possible to provide such a process
during the step of forming the non-optical
recombination elimination layer. Alternatively, the
removal of residual Al may be conducted in a process
25 of growing a GaAs layer interposed between the

process of forming the Al-containing layer and the
process of forming the non-optical recombination
elimination layer.

According to the present embodiment, it
5 becomes possible to form a highly efficient, reliable
surface-emission laser diode. Thereby, it is possible
to achieve the foregoing advantageous effect of the
present invention without increasing the number of
stacks in the reflector, as the non-optical
10 recombination elimination layer formed of the Al-free
$Ga_xIn_{1-x}P_yAs_{1-y}$ $(0<x\leq1, 0<y\leq1)$ layer is used in only
the low refractive index layer located closet to the
active region in the semiconductor Bragg reflector 12
or 18.

15 Further, it should be noted that filling of
polyimide is easily made, and thus, it is possible to
provide interconnection wiring forming the p-side
electrode, without risking the disconnection of the
wiring at the stepped part. Thereby, the reliability
20 of the device is improved further.

It was confirmed that the surface-emission
laser diode thus produced oscillates at the laser
oscillation wavelength of about 1.3μm.

In the present embodiment, it became
25 possible to construct a surface-emission laser diode

of long wavelength band on the GaAs substrate 11 by
using a GaInNAs layer containing Ga, In, N and As for
the major element. By forming a current confinement
structure by applying a selective oxidation process
5   to the AlAs layer 18_1 to form the oxide current
confinement layer 18_2, the threshold current of laser
oscillation is reduced effectively. In such a current
confinement structure, formed of the AlAs layer 18_1
in which the selective oxidation layer 18_2 is formed,
10   it is possible to provide the current confinement
structure close to the active layer, and lateral
diffusion of the injected electric current is
suppressed effectively. As a result of use of such a
current confinement structure, it becomes possible to
15   confine the careers effectively into a minute region
not exposed to the atmosphere. The foregoing current
confinement structure has another advantageous
feature in that the Al oxide constituting the layer
182 has a low refractive index and the efficiency of
20   carrier confinement is increased further. Thereby,
the efficiency of laser oscillation is improved
furthermore and the threshold electric current is
reduced. Further, the current confinement structure
has an advantageous feature in that formation thereof
25   is made easily and the production cost is reduced.

From the explanation noted above, the laser
diode of Figure 27 oscillates efficiently at the
wavelength of 1.3 μm similarly to the case of Figure
1. The laser diode of Figure 27 also has advantageous
5   feature of small power consumption and low production
cost.

The surface-emission laser diode of Figure
27 can be formed also by an MOCVD process, similarly
to the case of Figure 1. However, it is also possible
10   to use an MBE process or other growth process.
Further, it is possible to use nitrogen or a nitrogen
compound such as NH3 in an activated state.

Furthermore, it is possible to replace the
triple quantum well structure (TQW) in the active
15   layer 15 with other structure including different
number of quantum wells such as SQW structure, DQW
structure or MQW structure. Further, it is possible
to use a laser diode of different structure.

By adjusting the composition of the GaInNAs
20   active layer 15a in the surface-emission laser diode
of Figure 1, it becomes possible to realize a
surface-emission laser diode of the 1.55 μm band and
further the 1.7 μm band. In the present invention,
the GaInNAs active layer may contain other III-V
25   elements such as Tl, Sb, P, and the like. Further, it

is also possible to construct a surface-emission
laser diode of 1.3 μm band on a GaAs substrate by
using GaAsSb for the active layer.

        In the description heretofore, it was
5   assumed that the active layer contains Ga, In and Ss
as the major elements (GaInAs active layer) or Ga, In,
N and As as the active layer (GaInNAs active layer).
Further, the active layer may be formed of any of
GaNAs, GaPN, GaNPAs, GaInNP, GaNAsSb, and GaInNAsSb.
10 The present invention is particularly effective also
in these cases in which the active layer contains N.

        Figure 28 shows the room temperature
photoluminescence spectrum obtained for the active
layer that includes a GaInNAs/GaAs double quantum
15 well structure formed by a GaInNAs quantum well layer
and a GaAs barrier produced by an MOCVD process.
Further, Figure 29 shows the structure of the sample
used for the measurement.

        Figure 29 is referred to.
20   It can be seen that there are formed a
lower part cladding layer 202, an intermediate layer
203A, an active layer 204 containing therein nitrogen,
another intermediate layer 203B, and an and an upper
part cladding layer 205 consecutively on the GaAs
25 substrate 201.

Next, Figure 28 is referred to.

The curve A shows the result with regard to the sample that uses an AlGaAs layer as the cladding layer 202 and the double quantum well structure is

5   formed while interposing a GaAs layer similar to the intermediate layer 203A or 203B between the quantum wells. The curve B, on the other hand, shows the measurement result with regard to the sample that uses a GaInP layer as the cladding layer 202 and the

10 double quantum well structure is formed continuously while interposing a GaAs layer similar to the intermediate layer 203A or 203B.

As can be seen in Figure 28, the photoluminescence intensity of the sample A has

15 fallen off by one-half or more with respect to the photoluminescence intensity of the sample B. This means that there arises a problem of decrease of photoemission efficiency of the active layer when the active layer containing nitrogen therein such as

20 GaInNAs is grown continuously on a semiconductor layer that contains Al as constituent element such as AlGaAs while using a single MOCVD apparatus. Because of this, the threshold current density of the GaInNAs laser diode formed on an AlGaAs cladding layer is

25 increased by twice or more as compared with the case

in which the same laser diode is formed on an GaInP cladding layer.

The inventor of this invention conducted through investigation of this problem and obtained a knowledge explained below.

Figure 30 shows the depth profile of nitrogen and oxygen in the device for the case the cladding layers 202 and 205 are formed by an AlGaAs layer, the intermediate layers 203A and 203B are formed of GaAs, and the active layer is formed of the GaInNAs/GaAs double quantum well structure and the device is formed by using a single MOCVD apparatus. It should be noted that the measurement of Figure 30 was conducted under the measurement condition summarized in Table 1 by secondary ion mass spectrometry.

Table 3

first ion specie	Cs+
first acceleration voltage	3.0 kV
sputter rate	0.5nm/s
measurement area	160x256 μm^2
degree of vacuum	<3E-7Pa
polarity of measured ion	—

Figure 30 is referred to.

It can be seen that there appear two
nitrogen peaks in the active layer 204 in
correspondence to the GaInNAs/GaAs double quantum
5   well structure. Further, it is also noted that an
oxygen peak is detected in the active layer 204. On
the other hand, the oxygen concentration in the
intermediate layers 203A and 203, which are free from
N and Al, is lower in terms of one order as compared
10   with the oxygen concentration in the active layer 204.

Further, the depth profile of oxygen
measured about the sample having a constitution in
which the active layer 204 including therein the
GaInNAs/GaAs double quantum well structure is formed
15   on the cladding layer of GaInP together with the GaAs
intermediate layers 203A and 203B, has revealed that
the oxygen concentration in the active layer 204 is
in the background level.

Thus, it was confirmed experimentally that
20   the problem of oxygen incorporation into the active
layer 204 occurs singularly in the case in which the
laser diode has the nitrogen-containing active layer
204 in the state that the active layer 204 is
separated from the substrate by the semiconductor
25   layer 202 containing Al and the growth of the layers

constituting the device is conducted by a single
MOCVD apparatus while using a nitrogen compound
source material and an organic Al source material.
The oxygen atoms thus incorporated into the active
5   layer form a non-optical recombination state therein
and cause a decrease of luminous efficacy of the
active layer.

Thus, from the result of Figure 30, it is
concluded that oxygen incorporated into the active
10   layer is the cause the problem of decease of optical
emission efficiency in the device in which the Al-
containing layer is provided between the substrate
and the N-containing active layer. It is conceivable
that the origin of this oxygen contamination would be
15   the oxygen-containing material that has captured
residual oxygen in the deposition apparatus or the
impurity contained in the nitrogen compound source
material.

Next, the mechanism of oxygen incorporation
20   into the active layer 204 will be examined.

Figure 31 shows the depth profile of Al
obtained for the same sample of Figure 30. The
measurement was conducted by the secondary ion mass
spectroscopy similarly to the case of Figure 30 under
25   the measurement condition shown in Table 2.

Table 4

first ion specie	O2+
first acceleration voltage	5.5kV
sputter rate	0.3nm/s
measurement area	60 μ m ϕ
degree of vacuum	<3E-70Pa
polarity of measured ion	+

Figure 31 is referred to.

It can be seen that Al is detected in the active layer 204, which was formed without introducing an Al source material. Further, it is noted that the Al concentration in the GaAs intermediate layer 203A or 203B formed adjacent to the Al-containing cladding layer 202 or 205 is lower than the Al concentration in the active layer 204 by the order of one. This indicates that Al in the active layer 204 has caused diffusion from the Al-containing cladding layer 202 or 205 and has substituted Ga in the active layer 204.

On the other hand, Al was not detected in the active layer in the case that the N-containing active layer was grown on a semiconductor layer free from Al such as GaInP.

From this, it is concluded that Al detected

in the active layer 204 originates from residual Al such as residual Al source material or residual Al reactant or residual Al compound or residual Al remaining in the growth chamber or gas supply line

5   and has been incorporated into the active layer as a result of coupling with the nitrogen source compound or the impurity such as water contained in the nitrogen source compound. Further, it is concluded that the Al incorporation into the N-containing

10   active layer is inevitable when a semiconductor light emitting device having an Al-containing layer between the substrate and the N-containing active layer is grown continuously by a single epitaxial apparatus.

By comparing Figure 31 with Figure 30, it

15   is noted further that the two oxygen peaks in Figure 30 corresponding to the double quantum well do not coincide with the two nitrogen peaks but coincide with the peak profile of Al shown in Figure31. This results indicates that oxygen in the GaInNAs quantum

20   well layer has been incorporated into the active layer not with the nitrogen source but with Al in the form coupled with residual Al that has been incorporated into the quantum well layer.

More specifically, the residual Al source

25   material or residual Al reactant or residual Al

compound or residual Al in the MOCVD chamber is
thought to cause a coupling with water contained in
the nitrogen source compound or oxygen-containing
material remaining in the gas line or reaction

5   chamber and is incorporated into the active layer in
the form coupled with oxygen or water.

Thus, it was clarified by the inventor of
the present invention that, in the surface-emission
laser diode of a conventional GaAs system, there

10   occurs oxygen incorporation into the active layer and
oxygen thus incorporated has caused the problem of
decrease of efficiency of optical emission.

The foregoing discovery provides a clue to
the improvement of efficacy of the surface-emission

15   laser diode of the GaAs system in that it is
necessary to remove the impurity at least from the
part of the deposition apparatus used for the
production of the laser diode and may have a chance
to make a contact with the nitrogen compound source

20   material in the deposition chamber or the impurity
contained in the nitrogen compound source material.

Thus, by providing a step of removing the
residual Al after the growth of the Al-containing
layer but before the growth of the N-containing

25   active layer, it becomes possible to reduce the

concentration of Al and oxygen impurity incorporated into the active layer. By doing so, the concentration of residual Al source material or Al reactant or Al compound or Al concentration is already reduced when

5   the nitrogen compound source material is supplied for the growth of the N-containing active layer, and the reaction between the residual Al and the nitrogen source compound or the impurity contained in the nitrogen source compound is successfully suppressed.

10   It is further advantageous to remove the residual Al before the end of the growth of the non-optical recombination layer. By doing so, it is possible to suppress the non-optical recombination of carriers in the active layer at the time carriers are

15   injected into the active layer by way of current injection.

      For example, it became possible to carry out a continuous oscillation of the surface-emission laser diode of the GaAs system at room temperature

20   environment by reducing the Al concentration in the N-containing active layer to $1 \times 10^{19} cm^{-3}$ or less. Further, by reducing the Al concentration in the N-containing active layer to $2 \times 10^{18} cm^{-3}$ or less, optical emission characteristics substantially equal

25   to the case when the active layer is grown on an Al-

free semiconductor layer is obtained.

The removal of the residual Al source
material or residual Al reactant or residual Al
compound or residual Al from the part of the
5   deposition chamber that may have a chance to make a
contact with the nitrogen compound source material or
the impurity contained in the nitrogen compound
source material, can be advantageously conducted by a
purging process that uses a carrier gas as the purge
10   gas. Here, the time of the purging process is defined
as the time after the supply of the Al source
material into the deposition chamber is stopped in
correspondence to completion of the growth of the Al-
containing layer but before the start of supply of
15   the nitrogen compound source material to the
deposition chamber for the start of growth of the N-
containing semiconductor layer. It is also possible
to interrupt the growth of the intermediate layer,
which is free from any of Al and nitrogen, and
20   conduct a purging process by using the carrier gas as
a purging gas. In this case, the interruption of the
growth process of the intermediate layer may be
achieved after the start of growth of the Al-
containing layer until the midway of the growth of
25   the non-optical recombination layer.

Figure 32 shows an example of the semiconductor light-emitting device formed by providing such a carrier purging process. In Figure 32, those parts corresponding to the parts described

5   previously are designated by the same reference numerals and the description thereof will be omitted.

Thus, it can be seen that the Al-containing first semiconductor layer 202, the first lower part intermediate layer 601, the second lower part

10 intermediate layer 602, the N-containing active layer 204, the upper part intermediate layer 203, and the second semiconductor layer 205 are stacked consecutively the on substrate 201 in Figure 32.

In forming the structure of Figure 32, the

15 crystal growth is carried out by an epitaxial growth apparatus by using an organic-metal Al source and an organic nitrogen source material. In the case, the growth interruption process is provided before the start of growth of the second lower part intermediate

20 layer 602 but after the growth of the first lower part intermediate layer 601. During the growth interruption process, the part of the growth chamber that may make a contact with the nitrogen compound source material or the impurity in the nitrogen

25 compound source material is purged by a hydrogen gas

used as the carrier gas, such that the residual Al
source material or residual Al reactant or residual
Al compound or residual Al is removed.

Figure 33 shows the result of measurement

5   of the depth profile of Al concentration on a
semiconductor light-emitting device in which there
has been provided a growth interruption between the
first lower part intermediate layer 601 and the
second lower part intermediate layer 602 and a

10   purging process was conducted for 60 seconds.

Figure 33 is referred to. It can be seen
that the Al concentration in the active layer 204 is
reduced to 3 x $10^{17}cm^{-3}$ or less as a result of such a
growth interruption process and purging process. This

15   value of Al concentration is the same degree as the
Al concentration in the intermediate layers 601 and
602.

Figure 34 shows the depth profile of
nitrogen and oxygen for the device of Figure 32.

20   Figure 34 is referred to. It can be seen
that the oxygen concentration in the active layer 204
is reduced to 1 x $10^{17}cm^{-3}$, which is a background
level. The oxygen peak appearing in the lower part
intermediate layer 601 or 602 in Figure 34 is

25   interpreted as showing oxygen segregation to the

growth interruption interface as a result of
interruption of growth. Thus, it is preferable to
conduct the growth interruption period after the
termination of the growth of the semiconductor layer
5   containing Al but before the growth termination of
the non-optical recombination elimination layer, in
the case there is provided a growth interruption and
purging process. In the non-optical recombination
elimination layer, it is possible to increase the
10   bandgap energy as compared with the quantum well
active layer or barrier layer, and the adversary
effect of the non-optical recombination caused by the
oxygen segregated to the growth interruption
interface is effectively suppressed when career
15   injection is made into the active layer. The
constitution that uses the non-optical recombination
elimination layer provides a particularly
advantageous effect in the case of using an active
layer containing nitrogen.

20   In the semiconductor light-emitting device
of Figure 32, the impurity concentration level of Al
and oxygen in the nitrogen-containing active layer
204 is reduced successfully by interrupting the
growth process between the first lower part
25   intermediate layer 601 and the second lower part

intermediate layer 602 and by conducting a purging process for 60 minutes. In this way, the optical efficacy of the active layer 204 was effectively improved.

5　　　　　　Further, it is also possible to carry out the Al removal process while heating the susceptor during the purging process conducted with a carrier gas. By doing so, the Al source material or reaction product adsorbed on the susceptor or the region near 10　the susceptor is effectively decoupled and removed. In the case of conducting such a heating of the substrate during the purging process, it is necessary to supply the group V source gas such as AsH3 or PH3 so as to avoid thermal decomposition of the uppermost 15　semiconductor layer.

　　　　　　It is also possible to transport the substrate to a chamber different from the growth chamber when conducting the purging process with a carrier gas in an MOCVD apparatus. In the case that 20　the substrate is transported to another chamber from the growth chamber, it is not necessary to keep supplying the group V source gas such as AsH_3 or PH_3 to the growth chamber. Thereby, the efficiency of thermal decomposition of the Al reactant deposited on 25　the susceptor or the region surrounding the susceptor

is substantially facilitated and the efficiency of
removal of Al is improved.

Further, it is also possible to carry out
the purging process while continuing the growth of

5   the intermediate layer. In the constitution of Figure
27, for example, the non-optical recombination
elimination layer 13 is provided between the N-
containing active layer 15 and the reflector 12
formed of the AlGaAs material containing Al. Thereby,

10 the distance between the N-containing active layer 15
and the Al-containing layer is increased, and it is
possible to increase the duration of the purging
process in the case the purging process is conducted
simultaneously to the growth. In such a case, it is

15 advantageous to decrease the growth rate and increase
the purging time.

Further, it is also possible to carry out
the growth of the Al-containing reflector 12 of
AlGaAs material and the N-containing active layer 15

20 in respective, separate apparatuses. In this case,
too, the impurity concentration level of Al or oxygen
in the active layer 15 can be reduced, by setting the
regrowth interface below the non-optical
recombination elimination layer 13.

25 In the case that the surface emission laser

diode is produced with the crystal growth process
that does not use an organic-metal Al source or
nitrogen compound source material such as an MBE
process, there is no report about the degradation of
5   the optical efficiency in the semiconductor light-
emitting device in which N-containing active layer is
provided on the Al-containing semiconductor layer. In
case of an MOCVD process, on the other hand,
degradation of optical efficacy of the GaInNAs active
10   layer formed on the Al-containing semiconductor layer
is reported.

In Electron. Lett., 2000, 36 (21), pp.
1776-1777, for example, there is a report that the
photoluminescence intensity deteriorates remarkably
15   when a GaInNAs quantum well layer is grown
continuously on an AlGaAs cladding layer in the same
MOCVD growth chamber, even when an intermediate layer
of GaAs is provided on the AlGaAs cladding layer. In
the foregoing report, the GaInNAs active layer is
20   grown in a MOCVD chamber different from one used for
growing the AlGaAs cladding layer so as to improve
the photoluminescence intensity.

Thus, it is believed that the
aforementioned problem arises more or less when
25   growing a crystal layer by an organic-metal Al source

and a nitrogen compound source, as in the case of an
MOCVD process.

In the MBE process, the crystal growth is
carried out under a ultra low-pressure environment
5   (high vacuum state). On the other hand, an MOCVD
process is conducted under a process pressure of
several ten Torr to the atmospheric pressure. Thus,
the mean free path of the gaseous molecules is
overwhelmingly short in an MOCVD process as compared
10 with the MBE process. Because of this, it is
conceivable that the source gas molecules or the
carrier gas molecules make a contact with various
parts of the gas line, reaction chamber, and the like.

Thus, in the case of the growth process
15 that uses a relatively high pressure for the reaction
chamber or gas line as in the case of the MOCVD
process, it becomes possible to eliminate the
incorporation of oxygen into the N-containing active
layer, by providing a removal step for removing the
20 residual Al source material or Al reactant or Al
compound or Al from the location of the reaction
chamber, in which the reaction chamber may make a
contact with the nitrogen compound source material or
the impurity contained in the nitrogen compound
25 source material. Such a removal step should be

conducted after the growth of the Al-containing
semiconductor layer but before the start of growth of
the N-containing active layer. More preferably, the
removal process should be carried out after the
5   growth of the Al-containing semiconductor layer but
before the end of the growth of the non-optical
recombination elimination layer.

For instance, it is possible to evacuate
the gas line or the growth chamber with a vacuum
10 evacuation process after the growth of the Al-
containing semiconductor layer but before the growth
of the N-containing active layer. In this case, it is
preferable to carry out the evacuation process in the
state that the substrate is heated.

15 Also, it is possible to remove the residual
Al after the growth of the Al-containing
semiconductor layer but before the growth of the N-
containing active layer by supplying an etching gas.
For example, an organic compound gas may be used as
20 the etching gas that reacts with the Al-containing
residue.

For example, it is possible to cause a
reaction in the Al-containing residue by supplying a
DMHy gas, which is one of the organic compound gases,
25 at the time of the growth of the active layer from a

DMHy cylinder. Therefore it is possible to remove these Al-containing residue by causing a reaction between the Al-containing residue remaining on the reaction chamber surface, heating zone, or jigs used

5 for supporting the substrate, and the organic compound gas by supplying the organic compound gas from a gas cylinder, after the growth of the Al-containing semiconductor layer. By a method, too, it is possible to suppress the incorporation of oxygen

10 into the active layer. Particularly, by using the same gas as the gas used for the nitrogen source it is possible to avoid the problem of providing a special gas line. This process can be carried out while interrupting the growth or growing a dummy

15 layer containing nitrogen such as GaNAs, GaInNAs, GaInNP separately from the growth of the active layer. By doing conducting the Al removal process simultaneously to the crystal growth process, it is possible to reduce the time loss as compared with the

20 case of interrupting the growth process, and the throughput of the semiconductor device production is improved.

By using GaInAs in the active layer of laser diode, it became possible to realize a laser

25 diode oscillating at the wavelength of 1.2μm by

growing a highly strained GaInAs quantum well active
layer by using a low temperature growth process of
600℃. This wavelength value is substantially longer
than the wavelength of 1.1μm, which has been
5   conceived as the upper limit of laser oscillation
wavelength. Conventionally, there was no material
suitable for the laser diode of 1.1 - 1.7 μm. On the
other hand, it became possible to realize a highly
efficient surface-emission laser diode operable in
10   the wavelength band of 1.1 - 1.7μm, by using a
highly strained active layer of GaInAs, GaInNAs or
GaAsSb together with the use of the non-optical
recombination elimination layer. With this, the
possibility of applications to the optical-fiber
15   telecommunication systems was opened.

[Third Embodiment]

        Figure 35 shows a laser diode chip 32
including the long-wavelength surface-emission laser
20   diode of Figure 1 or Figure 27 explained previously.
The example that formed on an n-type GaAs wafer 31 of
a surface orientation (100) is shown.

        Figure 35 is referred to.

        It can be seen that a number of laser diode
25   chips 32 are formed on the GaAs wafer, and each of

the laser diode chips 32 carries thereon n laser
diodes each having a construction explained before.
The number n and arrangement thereof are decided
according to the use of laser diode chip 32.

5   Figure 36 shows the example of the optical
transmission/reception system using the long-
wavelength surface-emission laser diode having the
laser oscillation wavelength of 1.1-1.7 μm band.
Those parts explained previously are designated by
10   the same numerals and explanation is omitted.

Figure 36 is referred to.

The surface-emission laser diode chip 32 is
provided at the A point as an optical source such
that the emission part 32A of the laser diode chip 32
15   makes an optical coupling with the optical fiber 33.
The optical signal emitted from the emission part 32A
of the laser diode chip 32 is injected into the
optical fiber 33. The optical signal is transferred
in the direction shown with the thick arrow in Figure
20   36. The end point of the optical fiber 33 is located
at the B point. The photodiode or other suitable
photodetection device 34, which constitutes the
photodetection unit is provided in the B point, and
the optical detection part 34A thereof is coupled
25   optically to and the optical fiber 33. Thus, the

optical transmission/reception system is composed.

In this example, the location B for the photodetection unit and the location A for the optical source are tied with a straight line by the

5   optical fiber 33.

Figure 37 shows the construction of Figure 36 schematically.

Figure 37 is referred to.

The black circles A, B in the figure show

10   the location of the optical source 32 and the photodetection unit 34 respectively. A black thick line shows the optical fiber 33.

Conventionally, optical source 32 and photodetection unit 34 are connected optically with

15   optical fiber 33 that provides the transmission path and constitute an optical transmission/reception system. The transmission path is formed extending from several tens of meters to several tens of kilometers in the optical transmission/reception

20   system with the long-wavelength surface-emission laser diode of laser oscillation wavelength 1.1 - 1.7 μm band of this invention. Thereby, there may be obstacles between the points A and B.

For example as for Figure 38, obstacles 35A

25   and 35B exist between the points A and B. Thus, the

point B for the location of the photodetection unit
and the point A for the location of the optical
source cannot be connected with the transmission path
33 of a straight line. Thus, Figure 38 shows the

5   example of bending the transmission path by a right
angle.

     When the optical fiber 33 is bent at the
point where the transmission path is bent by a right
angle with the same angle as in the case of Figure 38,

10   the optical fiber 33 is damaged and stops functioning
as a transmission path. It is possible to provide a
reflection part in the bending part of the
transmission path so as to deflect the optical beam.
The use of the reflection part in such a bending part

15   of the transmission path increases the cost.

     Thus, the present invention proposes an
approach to bend the optical transmission path
without providing a reflection part and without
spoiling the functioning of the optical fiber 33 as a

20   transmission path.

     Figure 39 shows a third embodiment of this
invention. Those parts explained previously are
designated by the same reference numerals and
explanation is omitted.

25   Figure 39 is referred to. Obstacle 35C

exists between the A point and B point. The location

B and the location A for the photodetection unit and

the optical source 32, respectively, can not be

connected by a transmission path of straight line.

5 However, as shown in this embodiment, the location B

for the photodetection unit 34 and the location A for

the optical source 32 are connected by bending

optical fiber 33, which composes a transmission path

without causing a local angle. Thus, the optical

10 fiber 33 composing the transmission path is not

damaged by the bending, and it is possible to avoid

the obstacle 35C. According to the present invention

it is possible to construct a fine optical

transmission/reception system even when obstacles

15 must be avoided.

Figure 40 is another example according to

this invention. In this case obstacles 35D, 35E exist

between the points A and B. Location B and location A

of photodetection unit 34 and optical source 32,

20 respectively, can not be connected with a straight

line transmission path.

However, by bending the optical fiber 33 of

the transmission path, without causing a local angle,

as shown in this example of this invention it is

25 possible to connect the location B for the

photodetection unit and the location A for the optical source. As a result, the transmission path is bent continuously in this example of the present invention. It is not formed step-like and a local

5   angle is not required.

Furthermore the above explanation pertains to the optical transmission/reception system using the long-wavelength surface-emission laser diode with laser oscillation wavelength of $1.1 - 1.7 \mu$m band to

10 suitably provide middle to long distance telecommunication systems. According to this invention it is possible to deploy this system inside of a building, for example, even in the case of constructing an optical transmission/reception system

15 with a length of several centimeters to several meters. Even in this case, the transmission direction of the optical beam can be changed in all directions without providing reflection part , by bending the optical fiber along the transmission path, without

20 causing a local angle therein . According to evaluations conducted by the inventor of the present invention, there was not any case wherein the function of a transmission path failed due to the optical fiber 33 being bent, even in the case that

25 the transmission path was bent continuously as

indicated in Figure 40. There was no damage to the transmission paths such as those shown in Figure 39 and Figure 40, as long as the diameter of the curvature of the transmission path does not exceed 20

5   cm. To put it differently, the transmission path can be arranged to avoid obstacles such as shown in Figure 40, even if reflection part or the like, that changes the direction is not provided, if the diameter of the transmission path curvature does not

10 exceed 20 cm. Thus, the present invention provides a fine optical transmission/reception system that functions with high reliability at a low cost.

[Fourth embodiment]

15   Next the fourth embodiment of this invention is explained.

Figure 41 shows another example of an optical transmission/reception system using the long-wavelength surface-emission laser diode with laser

20 oscillation wavelength of 1.1 - 1.7 μm band. Those parts explained previously are designated by the same reference numerals and explanation is omitted.

Figure 41 is referred to. In this example the laser diode emission part 32 A is coupled

25 optically to an optical fiber F1. The laser beam that

is emitted from the laser diode emission part 32 A is transferred in the direction of the thick arrow in Figure 41. The laser beam that was transmitted through the optical fiber F1 is then bent 90 degrees

5 by a reflection part R. The laser beam then enters optical fiber F2. Optical fiber F2 at the end point couples optically to the light detector part 34A of the photodetection device 34 such as a photodiode. Thus the optical transmission/reception system is

10 composed.

It should be noted that the foregoing description is merely for the exemplary purpose of the optical transmission/reception system of this invention. Thus, only one laser diode emission part

15 32A is shown in the present example. However, it also is possible to construct, by using the advantageous feature of the long-wavelength surface-emission laser diode of the present invention, to construct a large capacity optical transmission/reception system of the

20 multiple laser array type, in which a number of laser diodes 32A are formed on one laser diode chip 32A and the optical transmission/reception system is constructed by using a number of optical fibers F1 and photodetection devices 34 coupled optically to

25 the laser diodes 32A.

Figure 42 shows another arrangement of the optical transmission/reception system of Figure 41. The optical transmission/reception system of Figure 41 may be a yard, whereas in Figure 42 it is arranged

5 inside a wall of a building. Those parts explained previously are designated by the same reference numeral and explanation is omitted.

Figure 42 is referred to.

A room 42 is defined with a wall 41 by

10 which the building is formed. Within a space 41 A inside the wall 41, a long-wavelength surface-emission laser diode chip 32 having laser oscillation wavelength of the 1.1 - 1.7 μm band is provided at the A point as an optical source. Further, The

15 photodiode that constitutes the photodetection unit 34 is provided in the B point. Also the reflection part R is provided in the space 41A so as to deflect the transmission path between the A point and the B point. Figure 42 shows the plan view of the room and

20 the optical transmission/reception system merely for the purpose of explanation. Because of this, the room or the wall and the optical transmission/reception system are not drawn to scale.

Furthermore, though not indicated by Figure

25 42, in each optical transmission/reception unit 32

and 34 at the points A and B, there maybe other
connect instruments or connectors. These may be in
the internal space 41 A of the wall 41, or may be in
the room 42.

5   Figure 43 shows the plan view of an optical
transmission/reception system in the room 42. Those
parts explained previously are designated by the same
reference numerals and explanation is omitted.

          Figure 43 is referred to. The laser diode
10 32 and the photodiode 34 are tied with one straight
line by the optical fiber F12 crossing the inside of
room 42. Therefore the optical transmission/reception
system is arranged on the floor, under the floor, or
in the ceiling of the room.

15   Figure 44 shows another example of the
optical transmission/reception system in the room 42.
Those parts explained previously are designated by
the same reference numerals and explanation is
omitted.

20   Figure 44 is referred to.

          In this case the laser diode 32 and the
photodiode 34 are tied by the optical fiber F12 by
curving the optical fiber F12 while utilizing the
flexibility of the optical fiber.

25   However, the optical fiber F12 has to be

arranged so as to cross the room 42, but it can
change the direction of the transmission path only
with big curvature even if it uses the flexibility of
optical fiber. However, the optical fiber has to be
5   bent with a large radius of curvature, and the
optical transmission/reception system has to be
constructed to or under the floor or in the ceiling
of room 42 in the state that the optical fiber 12
crosses the room 42. Thus, it is necessary to dispose
10 the optical fiber under the floor or on the floor or
on the ceiling.

In the arrangement shown in Figures 26 and
27 the optical fiber has to be arranged so as to
cross the room 42. Therefore, the optical fiber on
15 the floor, under the floor or in the ceiling of the
room is arranged in a very complicated and disorderly
manner. It gets more complicated when a plural
optical transmission/reception system is arranged.
Then there are the problems of intertwisting, and
20 maintenance after installation become difficult.
Especially, such an arrangement is very dangerous in
the case the optical fiber F12 is arranged on the
floor where a pedestrian can hook the foot.

The optical fiber transmission path of this
25 embodiment of the present invention is well-suited to

the wall 41 or pillar or other parts of the building,
because the optical fiber transmission path can be
bent 90 degrees by using the reflection part R as
shown in Figure 42 and is otherwise arranged

5   beautifully in appearance, even if it is arranged in
a place where it is not inside of wall 41 and can be
seen by the eye. It gets complicated if a plural
optical transmission/reception system is arranged,
but there is not a problem of the optical fibers

10   intertwisting. The maintenance after installation can
be done easily.

The reflection part R for the deflection of
the transmission path is provided, in constructing
such a peripheral (out of sight) optical

15   transmission/reception system in this embodiment. By
using the reflection part R, the transmission path is
able to be arranged effectively. Instead of exposing
the transmission path unnecessarily, the reflection
part material R puts the transmission path inside the

20   ceiling, under the floor or in the wall of a building.
The transmission path does not occupy area needlessly.
The building design comes to be produced effectively.
The degree of freedom for an aesthetic design
increases.

25   Furthermore the reflection part R is not

necessarily restricted to 90 degrees, in the case
that the direction of the transmission path is bent
by reflection part material R. However, in the normal
case, a building is executed/designed, unless there
5   is a demand for a special design, for pillars, walls,
floors, and ceilings to provide many cases where one
straight line crosses another straight line at 90
degrees. In such normal cases it is desirable for
reasons of esthetic beauty and of efficiency, when
10 the optical fiber transmission path changes 90
degrees, for it to be arranged along a pillar, wall,
floor, ceiling and the others.

        Also, exposing the optical fiber
transmission path to the eye unnecessarily be avoided
15 in constructing such an optical
transmission/reception system, by using the
reflection part material R for changes in direction
of the transmission path so that the transmission
path does not occupy area needlessly inside the
20 ceiling, under the floor or in the wall of a building.
Thereby the building design comes to be produced
effectively and the degree of freedom for aesthetic
design increases.

        Figure 45 shows an example of another
25 optical transmission/reception system of this

embodiment. The optical signal emitting from the
emission part 32 A of the laser diode 32, in this
example, is transferred in space. It goes straight
along the arrow of Figure 45. It is received with the
5   light detector part 34 A comprised of a photodiode
and other photodetection devices 34.

As explained according to the embodiments
of the present invention previously, it is preferable
to use a surface-emission laser diode equipped with
10   the improved semiconductor Bragg reflectors 12 and 18
further with the non-optical recombination
elimination layer and having the laser oscillation
wavelength band of 1.1 - 1.7 μm for the laser diode,
in view point of reliability, low power driving, and
15   low production cost. The foregoing wavelength was not
possible before in a surface emission laser diode.

The following description will be made for
the construction in which there is only one laser
diode. However, it should be noted that, in the case
20   of the long-wavelength surface-emission laser diode
of the 1.1 - 1.7 μm band, a number of laser diodes
are formed on a single chip with low cost, and it is
easy to construct a multiple laser array system.
Thereby, a large capacity telecommunication system us
25   realized.

Figure 46 is another example of the optical transmission/reception system of this embodiment. Those parts explained previously are designated by the same reference numerals and explanation is
5 omitted.

Figure 46 is referred to.

The optical signal emitted from the emission part 32A of laser diode 32 is transferred through space. It goes straight in the direction of
10 the arrow in Figure 46. The progress direction of the optical path is bent by a midway, for example by the reflection part R. The optical signal is received with the light detector part 34A comprising the photodetection devices 34 such as a photodiode, and
15 the like.

[Fifth Embodiment]

Conventionally the signal transmission of inside an electronic apparatus has been achieved by
20 using a conductor cable in the form of electrical signals. Therefore numerous conductor cables are connected inside various electronic apparatuses. The arrangement/processing of the conductor cable was complicated, presenting problems in the design stage
25 and with the assembling stage at the factory.

Thereupon, instead of exchanging of the signals by such conductor cable, in this embodiment of this invention the electrical signals are substituted for with optical signals by the optical

5   transmission/reception system as shown in Figure 45 or Figure 46. The optical signal that is substituted is transferred through space. Such substitution omits or decreases conductor cable. The conductor cable inside the instrument is decreased as much as

10   possible. Internal wiring is simplified. By simplifying the internal wiring of the electronic apparatus the complexity of the layout and processing of conductor cable is reduced. Reducing or eliminating the complexity can increase the degree of

15   freedom of each part/unit and other layout items inside the apparatus.

Electronic apparatuses for which the optical transmission/reception system of this embodiment of this invention is incorporated include,

20   for example, recording apparatuses such as a copying machine or laser printer that uses electrophotography, ink-jet recording apparatus, or recording apparatus using a silver salt photography process. In addition, the present invention can be used in computers, video

25   apparatuses, television sets.

As for Figure 47, the figure shows an electrophotographic copying machine 541 to which this embodiment is applied. Figure 48 enlarges Figure 47.

Figure 48 shows the internal structure of

5 the electrophotographic copying machine 541 schematically. Those parts explained previously are designated by the same reference numerals and explanation is omitted.

Figures 47 and 48are referred to.

10 The electrophotography copying machine 541 has a sheet feed cassette 542 and a sheet recovery tray 543. Furthermore wiring board 550 and image formation mechanism 549 including sheet feed mechanism 548 and photosensitive drum 546 are

15 connected by electrical circuit and included in the main body case that is closed with cover 547a and fitted to the case 547.

And also the photodiode 34 and the laser diode 32 are located in the case 547 respectively at

20 the point A and the point B, all previously explained. The laser diode 32 and photodiode 34 are connected optically, by the construction explained with Figure 41 previously and use optical fiber F1, the mirror R and optical fiber F2.

25 Figure 49 shows an ink-jet recording

apparatus 551, as another example to which the
present invention is suitably applied. Figure 50 is
the figure that enlarges Figure 49 and schematically
shows the internal structure.

5   Figures 49and 50 are referred to.

The ink-jet recording apparatus 551 has a
case 554 comprising a lower part case 554b and an
upper part case 554a. A sheet feed mechanism 555 and
an ink-jet recording head 556 are provided on the
10   upper part case 554a.

Figure 50 is referred to. The ink-jet
recording head 556 is provided so as to move right
and left on a carriage 556A. Image formation is
performed on the recording sheet that is pressed on
15   platen roller 558 by recording part 557.

Wiring board 559 provides an electronic
circuit in the lower part case 554b. Optical fiber
F12 similar to the embodiment explained above is
provided between the A point and B point in the
20   wiring board 559. Optical fiber 12 transfers the
optical signal to the photodetection device 34 at the
B point from the optical source of the laser diode
chip 32 provided at the A point.

According to this embodiment of the present
25   invention, conductor cable in the electronic

apparatuses is eliminated or reduced. Conductor cable is replaced inside the instrument by an optical transmission/reception system. The examples of an electrophotography copying machine and ink-jet

5   recording apparatus were shown in Figures 47 - 50, as the electronic apparatuses to which this embodiment is applied. This invention is not restricted to these apparatuses.

10   [Sixth Embodiment]

In the recording apparatuses such as an ink-jet recording apparatuses or recording apparatus of silver salt photography or an electrophotographic recording apparatus, there arises a problem in that

15   toners or ink or liquid developer form a mist. Further, dust particles such as paper dust may float inside the apparatus. Thus, the inside of such apparatuses is not an ideal environment for an optical transmission/reception system of this

20   invention.

In consideration this problem, the sixth embodiment of this invention shown in Figure 51 provides a cover member 32B covering the laser diode chip 32 or a cover member 34B covering the photodiode

25   34. For example, these cover members 32B and 34B are

formed by a transparent glass-like member. In Figure
51, those parts explained previously are designated
by the same reference numbers, and explanation
thereof will be omitted.

5   It is possible to use a high-precision
plastic member, from which strain is removed, in
addition to a glass, for the cover members 32B and
34B. Such a cover member provides physical and
chemical protection of the laser diode and the
10   photodetection device used in this invention that are
produced by a sophisticated process.

        Furthermore the toner, ink or paper dust
and other foreign matter cannot be allowed to adhere
to the laser diode chip of this invention and spoil
15   the function of the optical transmission/reception
system, such as shading of the laser beam. Therefore
it is desirable to form these cover members
detachable. By making the cover members detachable,
the cover members may be removed right away anytime
20   that foreign matter adheres. Furthermore a cover is
not provided to reflection member R in Figure 51. As
occasion demands a cover can be provided also to the
reflection member R.

        Considering the contamination originating
25   from toner and paper dusts, it is thought that it

would be more effective to provide such a cover
member 32B or 34B in the apparatuses such as a
printer or copying machine than a computer or a video
apparatus or a television set.

5

[Seventh Embodiment]

Figure 52 shows an example another optical
transmission/reception system that uses the long-
wavelength surface-emission laser diode having the
10 laser oscillation wavelength of 1.1 - 1.7 μm band.
Those parts explained previously are designated with
the same reference numerals and explanation is
omitted.

Figure 52 is referred to. This embodiment
15 concatenates and connects plural optical fibers along
the optical transmission path in the construction of
Figure 36. This embodiment enables an optical
transmission path of long distance. There are three
optical fibers in this example.

20 The optical telecommunication system was
previously studied with the wavelength of 0.85 μm.
However, the transmission loss of the optical fiber
was large at this wavelength and it was not practical.
On the other hand, it has been difficult previously
25 to compose the surface-emission laser diode

oscillating stably at a practical long wavelength
band in which the transmission loss becomes minimum
in the optical fiber.

In accordance with this invention, the
5   surface-emission laser diode that oscillating at the
wavelength band of 1.1 - 1.7 μm is realized by
improving the semiconductor Bragg reflector 12 or 18
and providing the non-optical recombination
elimination layers 13 and 17. Thus a practical long-
10   wavelength band optical telecommunication system is
now possible.

In the illustrated example, the laser beam
that emitted from the laser diode emission part 32A
of the long-wavelength surface-emission laser diode
15   chip 32 is injected into a first optical fiber FG1
for transmission, and the laser beam exited the first
optical fiber FG1 is injected to a second optical
fiber FG2 for further transmission. Furthermore, the
laser beam that exited this second optical fiber FG2
20   is injected into a third optical fiber FG3 for
transmission, wherein a the photodiode chip 34 having
the photodetector part 34A is coupled to the third
optical fiber FG3 for detection. Thus, the optical
fibers FG1, FG2 and FG3 are disposed along the
25   transmission path of the laser beam.

Between the laser diode chip 32 and the
first optical fiber FG1, there is provided an optical
connection module MG1 for connecting the laser diode
and optical fiber. Similarly, optical connection
5 modules MG2, MG3 and MG4 are provided between the
optical fibers or between the optical fiber and the
photodiode chip for optical coupling.

Figure 53 shows the bi-directional optical
transmission/reception system that has the
10 construction that provides transmission system FGA
corresponding to the system of the above Figure 52
and transmission system FGB inverted to the system of
the Figure 52. For the parts in the Figure 53 that
are the same as those explained above with the same
15 reference numerals, explanation is omitted.

Figure 53 is referred to.

The transmission system FGB includes, from
the right to the left, a third optical fiber FR3
transmitting the laser beam emitted from the laser
20 diode part 32A of the surface-emission laser diode
chip 32, a second first optical fiber FR2
transmitting the laser beam emitted from the optical
fiber FR3, a first optical fiber FR1 transmitting the
laser beam emitted from the optical fiber FR2, and
25 the light detector part 34A of the photodiode chip 34

is coupled optically to the first the optical fiber
FR1.

A connect module MR4 is provided between
the laser diode chip 32 and the third optical fiber
5   FR3 in the transmission system FGB, wherein the
connect module MR4 couples optically the laser diode
chip 32 and the optical fiber FR3. Similarly, there
are provided connect modules MR1, MR2 and MR3 are for
optical couplings respectively between the optical
10   fibers FR3 and FR2, between the optical fibers FR2
and FR1, and between the optical fiber FR2 and the
photodiode chip 34.

Figure 54 shows an example of parallel
optical telecommunication system in which n optical
15   transmission/reception systems each having the
construction of Figure 52 are arranged in parallel.

Figure 54 is referred to.

The plural laser emission part 32 A is
provided on a laser diode chip 32. Further, first,
20   second and third optical fiber groups MFG1, MFG2 and
MFG3 are constructed by a number of optical fibers
each corresponding to one of the plural optical
emission parts 32A. Further, there are provided a
number of photodetector parts 34A in the photodiode
25   chip 34 in correspondence to the plural laser

emission parts 32A.

In the present invention, in which the
surface-emission laser diode chip is used, it is easy
to provide a number of laser emission parts 32A on
5   the laser diode chip 32. By providing a number of
laser emission parts 32A on the laser diode chip, it
becomes possible to realize a large capacity
telecommunication system easily.

Furthermore it is possible to construct a
10   large capacity bi-directional optical
transmission/reception system that expands the
optical transmission/reception system of Figure 54,
in accordance with the construction of the bi-
directional optical transmission/reception system of
15   Figure 53 and using the optical fibers of plural
groups in parallel, although Figure 57 does not
indicate a bi-directional system.

[Eighth Embodiment]
20   Next another embodiment of this invention
will be explained.

Figure 55 shows the construction of an
optical connection module MG1 that is used to
optically couple the surface-emission laser diode
25   chip 32 and the first optical fiber group MFG1 in the

left part of Figure 54. Figure 55 shows optical connection module MG1 schematically with a rectangular dotted line.

5 Detailed construction of the optical connection module MG1 will be explained hereinafter with reference to Figures 39 - 59. Those parts explained previously are designated by the same reference numerals and explanation is omitted.

10 Figures 56 and 57 show the construction of the surface-emission laser diode chip 32 and the optical fiber group MFG1 respectively in the state before they are coupled and the state after they are coupled.

Figure 56 is referred to.

15 Optical connection module MG1 shown by a rectangular dotted line part schematically in Figure 55 is formed of a fiber holder 61 and a fiber holder 62 that holds each of the optical fibers fg1 that constitutes the optical fiber group FG1. The Fiber 20 holder 62 is inserted into chip holder 61 as shown in Figure 57 with arrows so as to face each other. Thus, the optical coupling is achieved between each of the laser diode emission parts 32A and the edge surface of the corresponding optical fiber fg1. Thereby the 25 desired optical coupling is achieved.

In the case of this invention, the holders
61 and 62 are provided with discrimination means such
that each of the laser diode emission part 32s A and
each of the optical fiber fg1 face with each other in
5   one-to-one relationship, without ambiguity in the
lateral or vertical directions. For this purpose, an
arrow mark is provided to each of the laser diode
chip holder 61 and the fiber holder 62 in the example
of the drawing. Thereby, optical connection can be
10   performed very efficiently, because of the ability to
discriminate the direction of holders 61 and 62
correctly and instantaneously at the time of the
connection between laser diode chip 32 and optical
fiber group FG1, at the time the optical
15   transmission/reception system of the present
invention is constructed.

Furthermore, the discrimination means is
not restricted to the arrow mark but it is also
possible to use a different color. Furthermore, the
20   discrimination means is not necessarily restricted to
the ones that can be visually recognized. It is
possible to have a discrimination means using the
tactile sense by utilizing the unevenness and other
features of form. It is possible to discriminate the
25   direction of holders 61, 62 briefly even in the case

of construction work in darkness or nighttime, in the
case that discrimination means able to discriminate
by the tactile sense is used.

Figures 58 and 59 show a different example
5   of the optical connection module MG1 that consists of
the combination of laser diode chip holder 61 and
fiber holder 62.

Figures 58 and 59 are referred to.

With the case as shown in Figures 39 and 40
10 this embodiment provides discrimination means to each
of laser diode chip holder 61 and fiber holder 62
similarly. So that it is possible to connect and
locate both holders accurately, in this embodiment a
flange surface is additionally formed so as to allow
15 the edge part of laser diode chip holder 61 engage
the fiber holder 62. The flange surfaces 61A and 62B
are shown in Figure 58.

Next is explained another feature of this
invention with regard to the discrimination means,
20 the location/connection means shown in Figures 56 -
59, and the optical connection module MG1 that causes
coupled light between the surface-emission laser
diode chip and the 1st optical fiber group. Yet the
concept of this invention is not only applied to
25 optical connection module MG1 that couples optically

the surface-emission laser diode chip and the first
optical fiber group MFG1 but it is also applied to
the optical connection module MG2 so that connects
the first optical fiber group MFG1 and the second
5 optical fiber group MFG2 optically.

Figure 60 shows an example of optical
connection module MG2 that couples optically such an
optical fiber group to a different optical fiber
group.

10 Figure 60 is referred to.

In this case, the means for discriminating
the direction is provided on the fiber holders 64 and
65 in the form of arrow mark such that that each
optical fiber fg1 of the first optical fiber group
15 MFG1 couples properly to the corresponding optical
fiber fg2 in the second optical fiber group MFG2. By
providing such discrimination means it becomes
possible to discriminate the a mutual direction
instantaneously at the time of the connection between
20 the first optical fiber group MFG1 and the second
optical fiber group MFG2, as the optical
transmission/reception system is constructed in
accordance with the present invention.

Furthermore, Figures 39-59 are examples of
25 the discrimination means and the present invention is

not limited to such an arrow mark. The discrimination
means might well use the difference of color. The
discrimination means might well be able to use the
tactile sense that senses the unevenness and others

5   of a certain form. By using the discrimination means
that is able to use the tactile sense, the advantage
is being able to feel the direction of the fiber
holder in the case of working during darkness, or
even in the case of performing construction work at

10 night.

In the construction of Figure 60, not only
the discrimination means is provided to each of the
first fiber group holder 64 and the second fiber
group holder 65, but there are formed the flange

15 surfaces on the edge part of the first fiber group
holder 64 (A part of Figure 60) and on the edge of
the second fiber group holder 65 (B part of Figure
60) such that the flange surfaces engage with each
other in the state that there is an optimum optical

20 coupling.

Furthermore, such discrimination means and
the location/connection means can be used also in the
optical connection module MG3 that couples the second
optical fiber group MFG2 and the third optical fiber

25 group MFG3 optically or in the optical connection

module MG4 that couples optically the third optical
fiber group MFG3 and the photodiode chip 34. When the
optical transmission/reception system is constructed
according to this invention, the mutual orientation
5   can be discriminated between the optical fiber groups
or between the optical fiber group and the photodiode
chip instantaneously and exact positioning and
optical coupling is achieved.

10   [Ninth Embodiment]

Furthermore, the optical connection module
according to another embodiment of the present
invention is accomplished by using plural optical
fibers in parallel. It should be noted that the
15   reason it has become possible to construct the large-
capacity optical transmission/reception system for a
distance from several centimeters to several hundred
kilometers is that stable laser oscillation of
surface-emission laser diode at the wavelength of 1.1
20   - 1.7μm wavelength has become possible as a result
of the present invention as noted before. By using
the surface-emission laser diode of the 1.1 - 1.7μm
oscillation wavelength, the inspection of laser
elements in the laser diode array is substantially
25   facilitated. Further, the productivity of the optical

transmission/reception system is improved remarkably.
Construction of such an optical
transmission/reception system was not possible in the
conventional surface emission laser diode of 0.85 μm

5   wavelength band. By using the surface-emission laser
diode the present invention, it became for the first
time possible to realize a commercial base optical
transmission/reception system.

Figure 61 shows another example of the

10 telecommunication system that uses a long-wavelength
surface-emission laser diode. It should be noted that
Figure 61 shows an optical fiber 72 drawn out from a
module package 71 in which a surface-emission laser
diode chip is accommodated and an optical fiber 73

15 for telecommunication that is connected to the
optical fiber 72. In Figure 61, those parts explained
previously are designated by the sane reference
numerals and explanation is omitted.

Figure 61 is referred to.

20 The optical fiber 72 drawn out from module
package 71 via the connector 71A is connected by
welding or other methods to the optical fiber 73 for
telecommunication at fiber connection part 74. In
this case, a predetermined connection margin is

25 required. With regard to the optical fiber cable 72

drawn out from the module package 71, when the

optical fiber length Lg shown in Figure 61 is too

short, a very fine work is needed to assemble the

module package 71. Thereby, the production cost is

5   increased. Also it becomes difficult to produce a

high-precision module.

         The optical fiber used in the

telecommunication systems of this invention is a very

minute thing. The diameter is only a 50 μm or 62.5 μm

10   in the typical case. When assembling the module

package 71 by using such an optical fiber, for

example, it is unnecessary to hold the optical fiber

72 extending from the module package 71 by using a

pair of tweezers. Thereby, it is difficult to hold

15   the optical fiber 72 unless the length Lg of the

optical fiber 72 is less than a certain length.

         Much of the assembling work can be done by

an automation apparatus. Even in such a case, a tool

is necessary for holding such a minute optical fiber.

20   In consideration of easiness of holding the distal

end part of the optical fiber by the holding tool, it

is necessary to secure a certain length Lg for the

optical fiber 72.

         The inventor of the present invention,

25   recognizing the importance of doing the assembly work

smoothly, conducted and evaluated extensive assembly
of optical fiber systems. Through various kinds of
experimental production operations, it was determined
that length Lg shown in Figure 61 must be at least 1

5   mm. In other words, the length Lg (the guide optical
fiber length Lg shown in Figure 61) of the optical
fiber 72 drawn out from the module package 71, in
which the surface-emission laser diode chip is
accommodated, has to be set to one or more

10 millimeters.

In the case the length of this part is
reduced to the order of microns comparable to the
optical fiber diameter, assembling work has to be
done under a microscope, using equipment that is

15 expensive and high-precision and highly mechanized.
Such work is unrealistic from industrial view point.

It should be noted that such a guide
optical fiber 72 is connected to the optical fiber
constituting a part of the optical telecommunication

20 system shown in Figure 61 by welding. Thereby, there
is a need to secure a welding margin (margin Gm shown
in Figure 62) in view of melting of the fiber edge of
the guide optical fiber 72. The welding margin would
be the order of millimeters.

25   The inventor of the present invention

conducted welding experiments and evaluated the
necessary length of the welding margin Gm of Figure
62.

In the case that guide optical fiber length

5   Lg is in the order of microns, it was discovered that
the fiber edge of the optical fiber 71 melts
excessively. For example, in the case the length Lg
is 200 μm, 500 μm or 900 μm, the edge surface of
optical fiber 71 melted excessively and a fine joint

10   was not obtained. On the other hand, it was confirmed
that a fine joint can be obtained in the case the
length Lg is made to be one millimeter or more, such
as 1 mm or 3 mm.

In summary, it is concluded that assembling

15   of then module package 71 requires that the length Lg
be one or more millimeters in order to connect with
the optical fiber of the optical telecommunication
system to the guide optical fiber.

With regard to the upper limit of the guide

20   optical fiber 72, it is sufficient for module
assembly work to secure the length of 20 mm for the
guiding purpose. In the case the optical fiber 7 is
too long, the excessive optical fiber can be cut
after the assembling of the optical module 71 to a

25   suitable length.

Next is an explanation about another aspect
of this embodiment.

The above explanation discussed the
relation with the surface-emission laser diode 32
5   acting as the optical source and the guide optical
fiber 72, while the same relation holds also at the
detecting side.

While illustration is omitted, it is
possible to realize a photodetection unit by
10   replacing the surface emission-laser diode 32 of
Figures 61 and 62 with the photodetection device 34
such as photodiode. Thereby, there is an optical
fiber corresponding to the guide optical fiber 72 of
Figures 61 and 62 in direct contact with the
15   photodetection device 34.

The same thought is necessary with regard
to the module assembling and connection to the
optical telecommunication system in the side of the
photodetection device.

20   In the present invention, a highly reliable
and practical assembling of the photodetection unit
is achieved by setting the length of the guide
optical fiber connected directly with the
photodetection device 34 (corresponding to the guide
25   optical fiber 72 of Figures 61 and 62) to one

millimeter or more. Further, a reliable connection is achieved with the optical fiber of the optical telecommunication system.

With regard to the upper limit, a length of
5   20 mm is sufficient similarly to the module package for the optical source side.

[Tenth Embodiment]

Figure 63 shows the example of a
10   telecommunication system that uses the long-wavelength surface-emission laser diode chip 32 with the laser oscillation wavelength 1.1-1.7 μm band with plural optical fibers. Those parts explained previously in the Figure 63 are designated with the
15   same reference numerals and explanation is omitted.

In the construction of Figure 63, the laser diode 32A in the laser diode chip 32 is driven by a communication control unit 81 via a laser diode driver circuit 82. The optical signal is supplied to
20   the optical fibers 72 and 73 in the form of an optical beam.

Conventionally, an optical telecommunication system was studied by using the laser oscillation wavelength of 0.85 μm. However,
25   because of the large transmission loss in the optical

fiber, it was not practical for long distance
telecommunication. Further, in the case of the
telecommunication system that uses the plural optical
fibers in combination of conventional edge-emission
5   type laser diodes, there is a need of adjusting the
optical coupling for each the optical fibers with
each of the laser diodes. Thus, the adjustment
process was complicated. Further, it was difficult to
connect the laser diodes directly to form a two
10   dimensional array. Further, in an edge-emission laser
diode, the emission angle of the laser beam is large
and the laser beam generally has a large aspect ratio.
Thus, it has been provide a coupling lens between the
emission part and the optical fiber for better
15   optical coupling efficiency.

Contrary to the prior art, a stable drive
is realized with low energy and low heating by using
the long-wavelength surface-emission laser diode of
$1.1 - 1.7 \mu$m band according to this invention.

20   Figure 64 shows the construction of the
surface-emission laser diode of the 1.3μm band
according to this invention. The emission angle of
the laser beam in such a surface-emission laser diode
is smaller as compared with an edge-emission laser
25   diode and takes the value of about 15 degrees in both

the vertical and horizontal directions. The laser
beam form is circular, and there is no need of
shaping the laser beam.

Thus, individual laser diodes 32A can be
connected with corresponding optical fibers 72
without using a coupling lens, as long as the
irradiation diameter of the laser diode is smaller
than the core diameter of the optical fiber 72. The
same is true also in other long-wavelength bands.

Thus, by using a surface-emission laser
diode according to the present invention, the
difference between the irradiation diameter of the
laser diode 32A and the optical fiber core diameter
provides a tolerable margin, and it becomes possible
to adjust plural optical fibers altogether.

As shown in Figure 64, the laser beam that
is emitted from an emission part, in other words, the
laser diode 32A, is injected with high efficiency
into the core at the edge surface of the optical
fiber. The optical signal thus injected into the
optical fiber is transmitted over a long distance
with little transmission loss due to the long the
wavelength of the optical signal. By using plural
optical fibers, a very high quality optical
telecommunication system of practical value is

materialized. The laser diodes 32A can form in arbitrary two-dimensional arrangement in the surface-emission laser diode chip 32 as long as they do not cause interference.

5   The plural optical fibers 72 are fixed with each other by using a jig 91 shown in Figures 65A - 65C, in which each of the optical fibers is provisionally fixed by the jig 91 and pouring a resin 92 into the jig as represented in Figure 65C. Thereby,

10   the positional adjustment can be omitted at the time of system construction, by providing a positioning guide in the connector connection part 71A. Thus, it becomes possible to easily construct an optical telecommunication system while using plural optical

15   fibers.

        Meanwhile, the number of the optical fibers used in an optical telecommunication system changes depending on the system. Thus, it is advantageous to design the system such that the number of optical

20   fibers can be changed flexibly.

        Thus, as shown in Figure 66B, a number of openings having the size of the optical fiber diameter are formed on the connector connection part 71a, and the connector connection part 71a is

25   attached on the surface-emission laser diode chip 32

of Figure 49C with an adjustment. Further, several
kinds of connectors 71b carrying plural optical
fibers as shown in Figure 66A are provided, and one
of the connectors 71b is selected and inserted into

5   the connector connection part 71a. By using such a
construction, waste of optical fibers in the optical
connector 71A is eliminated, and it becomes also
possible to add optical fibers later according to the
needs. Thereby, it becomes possible to increase the

10   degree of freedom of design of the optical
telecommunication system.

       Furthermore, in long-wavelength surface-
emission laser diode chip 32 of $1.1 - 1.7\mu$m band of
this invention, the laser diode elements constituting

15   the emission part 32A can be arranged in two-
dimensional array. In view of this, each optical
fiber 95 is provided with a resin coating 96 having a
hexagonal cross section as shown in Figure 67 such
that the two-dimensionally arranged optical fibers do

20   not contact directly with each other. Thereby, an
optical cable having a closest packing structure for
the optical fibers is realized as represented in
Figure 68. In the optical fiber cable of Figure 68,
the cross-sectional area of the optical fibers is

25   minimized because of the closest packing arrangement

of the optical fibers.

In the construction of Figure 67, it is also possible to use a fixing member of a resin having a number of holes of hexagonal arrangement for

5   holding the optical fibers, in place of providing a resin coating 96 outside the optical fiber 95.

[Eleventh Embodiment]

Figure 69 shows an example of the optical

10 fiber 101 used in a telecommunication system that uses a long-wavelength surface-emission laser diode. Those parts explained previously are designated by the same reference numerals and the description thereof will be omitted.

15 Figure 69 is referred to. The optical fiber 101 is injected with the laser beam emitted from the laser diode emission part 32A. The optical fiber 101 consists of cladding 101B enclosing a core 101A, and the core 101 A transmits the laser beam thus injected.

20 The diameter D of the core 101A is determined with regard to the length L so as to satisfy the condition $105 \leqq L/D \leqq 109$.

Conventionally, an optical telecommunication system was studied by using the

25 laser oscillation wavelength of the 0.85μm band.

However, the transmission loss of the optical fiber

was too large and there was no practical value. Also

there was no laser diode that can oscillate stably in

the long-wavelength band, in which the transmission

5   loss is minimum, was not realized. In accordance with

the present invention, a surface-emission laser diode

oscillating stably at the laser oscillation

wavelength of 1.1 - 1.7μm band is materialized as a

result of improvement of the semiconductor Bragg

10   reflectors 12 and 18 and by the provision of the non-

optical recombination elimination layers 13 and 17.

As a result, a practical long wavelength band optical

telecommunication system became possible.

Figure 70 shows the construction of a long

15   distance optical telecommunication system using the

above long-wavelength surface-emission laser diode

chip 32 and the optical fiber 101.

Figure 70 is referred to. The long distance

optical telecommunication system uses the long-

20   wavelength surface-emission laser diode chip 32. The

optical fiber is injected with the laser beam that is

emitted from the laser diode emission part 32A of the

laser diode chip 32. Further, the optical

telecommunication system includes a first optical

25   fiber 101A having the core diameter D of 50μm and

the length L of 5 km and second optical fiber having

the core diameter D of 50 μm and the length L of 5 km

injected with the laser beam emitted from the optical

fiber 101A, wherein the optical telecommunication

5   system further includes the photodiode chip 34

including the photodetector part 34A injected with

the laser beam emitted from the second optical fiber

101B.

Between the laser diode chip 32 and the

10   first optical fiber 101 A, the connection module 71

is provided, and a similar connection module 75 is

provided between the second optical fiber 101B and

the photodiode chip 34. Furthermore a repeater 101C

is provided between the first optical fiber 101A and

15   the second optical fiber 101B for amplification and

the repeating of the optical signal.

In the constitution of Figure 70, it should

be noted that the first and second optical fibers

101A and 101B are produced usually with several

20   thousand kilometers as a unit. However, a length of

several hundred kilometers becomes the unit of the

optical fiber product due to existence of pores or

other defects that occur during the production

process. In consideration of transmission loss, the

25   practical length of the optical fiber to the repeater

101C is 5 - 50 km in the case the optical fiber has a core diameter of 50 μ m. The optical fiber of this length is used for the optical fiber telecommunication.

5   In the case the transmission length is longer than 50km, it is necessary to provide a relay point for signal amplification in view of the transmission loss. When the distance is shorter than 5m, various telecommunication means are available

10   other than the optical telecommunication system.

For optical fiber 101 used with this embodiment, a quartz glass optical fiber having a core diameter D of several microns, or a plastics optical fiber having a core diameter D of several

15   hundreds microns may be used. These optical fibers can be used alone or in the form of a bundle.

Figure 71 shows an optical telecommunication system for bi-directional optical telecommunication by using a bundle of quartz glass

20   optical fibers 101-A and 101-B each having a diameter D of 50 μ m and a transmission length L of 500 m, wherein these optical fibers are separated from each other at the photodetection end and the optical source end.

25   Figure 71 is referred to.

There can be seen that optical
transmission/reception parts 102A and 102B are
provided in the present invention in which the long-
wavelength surface-emission laser diode chip 32 and

5   the photodiode chip 34 form a pair. Thus, the first
optical fiber 101A is coupled to the emission part
32A of laser diode chip 32 in the optical
transmission/reception part 102A, and the optical
fiber 101 A is further coupled optically to the

10   optical detection part 34 A of photodiode chip 34 in
the optical transmission/reception part 102B.
Similarly the second optical fiber 101B is coupled
optically to the emission part 32A of the laser diode
chip 32 in the optical transmission/reception part

15   102B, and the optical fiber 101B is coupled optically
to the optical detection part 34A of photodiode chip
34 in the optical transmission/reception part 102A.
Thereby, the laser diode chip 32 and the photodiode
chip 34 constituting the optical

20   transmission/reception part 102A form the connection
module 71. Also, the laser diode chip 32 and the
photodiode chip 34 constituting the optical
transmission/reception part 102B form the connection
module 75.

25   By expanding the foregoing construction of

using the long-wavelength surface-emission laser
diode chip 32 and the photodetector chip 34 as a pair
for the case in which a number of laser diode
elements 32A are formed on the laser diode chip 32
5   and a number of photodiode elements are formed on the
photodetector chip 34, it is possible to realize a
large capacity optical telecommunication system.

        Figure 72 shows the case of applying the
present invention to a high speed multimedia network
10   that uses a fluorinated plastic optical fiber having
a core diameter of 100μm and the transmission length
of less than 100m.

        Figure 72 is referred to.

        A first optical fiber 111 having a core
15   diameter D of 50μm extends from a station-side
apparatus 110 and a second optical fiber 112, formed
by bundling 50 optical fibers each having a core
diameter D of 50μm and a length of 1 km, is
connected to the optical fiber 111. As a result,
20   there is formed a the high speed optical transmission
system capable of transmitting information with the
speed of the order of Gbps with a total distance of
100 km. In the example of Figure 72, the optical
repeater 111R is provided between the optical fiber
25   111 and optical fiber 112, to compensate for the

damping of the signal by the propagation loss of quartz glass optical fiber.

The optical signal transmitted through the second the optical fiber 112 enters into a network

5 terminator 115 at first and converted to an electric signal. Further, the electric signal is distributed to necessary lines 115a - 115c, and the electric signal thus supplied to each line is transmitted further in the form of the optical signal by an

10 optical telecommunication system 116 that includes the optical transmission/reception parts 102A and 102B explained to with reference to Figure 71. The optical signal thus transmitted is supplied to a corresponding optical output port. In the optical

15 telecommunication system 116, an optical fiber 117a having a core diameter of 100μm and a length of 10 m is used for the optical transmission to the optical output port corresponding to the line 115a, while an optical fiber 117b having a core diameter of 100μm

20 and a length of 50m is used for the optical transmission to the optical output port corresponding to the line 115b. Further, an optical fiber 117c having a core diameter of 100μm and a length of 100 m is used for optical transmission to the optical

25 output port corresponding to the line 115c. The

optical signals thus transmitted are converted to
electric signals by the optical
transmission/reception part 102B in each optical
output port and is supplied to corresponding terminal
5   devices 102C.

Further, the transmission from each
terminal device 102C is transmitted to the optical
transmission/reception part 102 A in the form of an
optical signal through the optical fibers 117a - 117c
10 and reaches the station-side apparatus 110.

In this embodiment, the core diameter of
the optical fibers 117a - 117c has a large value of
100μm, and high-precision alignment by using a high-
precision lens system is not necessary. Thus, it
15 becomes possible to achieve optical connection to
various apparatuses in a home or office quite
extremely.

In the present embodiment, too, the
relationship of $105 \leqq L/D \leqq 109$ is maintained between
20 the length L and core diameter D of the optical
fibers. When the transmission distance is longer than
100 km, no substantial transmission is possible due
to the transmission loss, and thus, it is necessary
to provide a relay point for amplification and
25 repeating. In the case the transmission distance is

shorter than 10m, such an optical telecommunication system is not always necessary and may be replaced with other means.

Figure 73A and 73B show the application of

5   the long-wavelength surface-emission laser diode of the present invention to a hybrid optical integrated circuit device, respectively in a plane view and a cross-sectional view.

Figures 73A and 73B are referred to. The

10   long-wavelength surface-emission laser diode chip 32 and the photodiode chip 34 are carried on a ceramic substrate 51 in this embodiment. Further, the ceramic substrate 51 carries thereon a first optical waveguide 52 having a rectangular cross-section of 7

15   x 7μm and a length of 1 cm for guiding the laser beam emitted from the laser diode 32A. Further, the ceramic substrate 51 carries a second optical waveguide 53 having a rectangular cross-section of 7 x 7μm and a length of 1 cm similar to the optical

20   waveguide 52 in optical coupling with the photodetector part 34 A of the photodiode chip 34 for supplying the optical signal to the photodetector part 34B. Further, a preamplifier 51 for amplifying the output electric signal of the photodetector chip

25   34 is provided on the ceramic substrate 51.

Further, an optical fiber 54 having a core diameter D of 100 μm and a length of 100 m is provided in optical coupling with the first optical waveguide 52 via a connection module 56, and a second

5 optical fiber 55 having a core diameter D of 100 μm and a length of 100 m is provided in optical coupling with the second optical waveguide 53.

Further, a connection module 57 equipped with the surface-emission laser diode chip 32 and the

10 photodiode chip 34 is provided at the other end of the optical fibers 54 and 55 such that the optical fiber 54 is coupled with the photodetector part 34 A of the photodiode chip 34 and the optical fiber 55 is coupled with the laser diode 32 A of the laser diode

15 chip 32.

The optical waveguides 53 and 54 are formed on a silicon substrate 58 by the steps of forming the respective cores and the claddings that cover the cores by a photolithographic process, and the silicon

20 substrate 58 is provided on the ceramic substrate 51 commonly with the preamplifier 51A.

[Twelfth Embodiment]

Figures 74A and 74B show an example of a

25 laser diode chip 120 that is used with the optical

telecommunication system in which the long-wavelength surface-emission laser diode of the present invention is used, wherein Figure 74A shows a plane view while Figure 74B shows a cross-sectional view taken along a

5 line A-A'. It should be noted that the scale Figure 74A is not identical with the scale of Figure 74B. In the drawings, those parts explained previously are designated by the same reference numerals and the description thereof will be omitted.

10 Figures 74A and 74B are referred to.

It can be seen that the long-wavelength surface-emission laser diode 32A and the photodetection device 34A are formed to monolithically on a laser diode chip 120.

15 The photodetection device 34A has a stacked structure similar to the stacked structure of the long-wavelength surface-emission laser diode 32A and is formed simultaneously with the process of forming the surface-emission laser diode 32A. The structure

20 thus formed can be used as a photodetection device, by applying with a reverse bias or using without a bias. This photodetection device 34A has sensitivity to the oscillation wavelength of the surface-emission laser diode 32A and can detect the optical emission

25 of the laser diode 32A.

As will be understood from the plane view of Figure 74A, the photodetection device 34A is formed in such a form to surround the long-wavelength surface-emission laser diode 32A. On the top surface

5 of the laser diode 32A, an upper electrode 121 is formed and a lower electrode 123 is formed on the bottom surface of the laser diode chip 120. Also another upper part electrode 122 is formed on the top surface of the photodetection device 34A. An optical

10 window is formed in the upper part electrode 121 of the laser diode 32A for taking out the optical output. Such a window is not formed in upper part electrode 122 the of photodetection device 34A.

Figure 75 is the figure that explains the

15 operation of the laser diode chip 120 shown in Figure 74.

Figure 75 is referred to.

The laser diode 32A in the surface-emission laser diode chip 120 is positioned so as to face the

20 end surface of an he optical fiber 125, and the optical beam emitted from the surface-emission laser diode 32A is injected into the core of the optical fiber. Thereby, there occurs a leakage light in the lateral direction from the sidewall of the surface-

25 emission laser diode 32A, and the leakage light is

detected by the photodetection device 34A provided
adjacent to the laser diode. While the amount of the
leakage light from the sidewall of the surface-
emission laser diode 32A is not much, nevertheless

5   the leakage light is detected by the photodetection
device 34A, as the photodetection device 34A is
formed so as to surround the surface-emission laser
diode 32 A in the construction of Figure 75.

Furthermore, it should be noted that the

10 semiconductor Bragg reflector 18 and the upper part
electrode 122 are formed on the photodetection device
34 A in Figure 75. Therefore, the optical signal and
the like transmitted from another party via the
optical fiber 125 is reflected at the surface of the

15 photodetection device 34A as shown with the arrow in
the drawing. Thereby, the photodetector 34A does not
detect such an optical signal.

As it will be clear from the aforementioned
explanation, the present invention forms the

20 photodetection device for detecting the output
detection of the surface-emission laser diode
integrally on the surface-emission laser diode chip.
By integrating such a laser diode chip on a ceramic
substrate 111, it becomes possible to construct the

25 optical telecommunication system having a hybrid

constitution.

Figures 76A and 76B show an example of the
semiconductor laser diode chip used with the optical
telecommunication system in which the long-wavelength
5   surface-emission laser diode of this invention is
used, wherein Figure 76A shows a plane view while
Figure 76B shows a cross-sectional view that taken
along a line A-A'. The scale of Figure 76A and Figure
76B are not the same.

10   Figures 76A and 76B are referred to.

The long-wavelength surface-emission laser
diode 32A and the photodetection device 34A are
integrated monolithically on a laser diode chip,
wherein the photodetection device 34A has a stacked
15   structure similar to the stacked structure of the
long-wavelength surface-emission laser diode 32A.

Thus, the photodetection device 34A is
formed simultaneously with the same process as the
one used for forming the surface-emission laser diode
20   32A. The photodetection device 34A thus formed has
sensitivity to the wavelength of the surface-emission
laser diode 32A and can detect the optical radiation
produced by the laser diode 32A.

In the present embodiment, the upper
25   semiconductor Bragg reflector 18 is removed from the

photodetection device 34A by an etching process. As
can be seen from the plane view of Figure 76A, the
photodetection device 34A is formed so as to surround
the long-wavelength surface-emission laser diode 32A,
5   and the devices 32A and 34A have respective top
surfaces provided with the upper electrode 121 and
the upper electrode 122 formed with the window for
optical input/output. Further, the bottom electrode
123 is formed on the bottom surface of laser diode
10   chip 120.

         Figure 77 explains the operation of the
laser diode chip of Figure 76.

         Figure 77 is referred to.

         In the surface-emission laser diode chip
15   120, the laser diode 32A is positioned so as to face
the end surface of the optical fiber 125 such that
the optical beam emitted from the surface-emission
laser diode 32A enters into the core of optical fiber
125.

20   In this embodiment, the sidewall of the
surface-emission laser diode 32A and the sidewall of
the photodetection device 34A are covered with the
upper part electrode 121 or 122, and the leakage
light is not formed at the side wall of the laser
25   diode.

Thereupon, when an optical beam carryhinig
an optical signal comes in from another party on the
line, the optical beam emitted from the end surface
of the optical fiber 125 enters into the top surface
5   of the photodetection device 34A while causing
spreading as represented by an arrow in the drawing.
The optical beam is then detected by the
photodetection device 34A formed so as to surround
the surface-emission laser diode 32A. On the other
10   hand, the top surface of surface-emission laser diode
32A is covered with the semiconductor Bragg reflector
18, and because of this, no substantial optical beam
invades inside the surface-emission laser diode 32A
from outside.

15   Thus, as will be clear from the
aforementioned explanation, it becomes possible to
construct an optical telecommunication system having
an optical transmission/reception unit of hybrid
construction in the present embodiment, by forming
20   the photodetection device 34A for monitoring the
output of the surface-emission laser diode 32A
integrally on the surface-emission laser diode chip
120. Such a laser diode chip 120 can be integrated on
the ceramic substrate 111.

25   Furthermore the combination of the surface-

emission laser diode and the photodetection device

that explained above is merely for the purpose

showing an example, and the present invention also

includes the case of forming an array of these

5   devices or the case of combining the monitoring

photodetector 34A for monitoring the output of the

surface-emission laser diode 32A and the

photodetector 34A for detecting the incoming signals

are combined. Naturally, the present invention is not

10   limited to the specific mutual positional

relationship or shape of the surface-emission laser

diode and the photodetector.

[Thirteenth Embodiment]

15   Next, this invention will be explained

about other examples.

             It is important to use a highly strained

layer of GaInAs, GaInNAs or GaAsSb for the active

layer in order to realize the long wavelength surface

20   emission laser diode of $1.1 - 1.7 \mu$m. In order to

achieve this, it is necessary to minimize the

mechanical stress applied to the laser diode. Such a

mechanical stress may result from the thermal stress

caused between the laser diode and the mount

25   substrate as a result of the operational temperature

environment or due to the heating of the laser diode
or driver circuits. Such a thermal stress is caused
in a structure in which materials of different linear
thermal expansion coefficients are fixed, due to the

5 tendency of the structure that tends to maintain
original shape. Thus, the thermal stress depends on
the temperature change, the coefficient of linear
thermal expansion, Young modulus, and the like. It is
possible to eliminate the thermal stress by

10 controlling the temperature of the whole module
including the laser diode. However, such a measure of
providing a temperature regulating mechanism is
difficult in view of the increased cost. Further, it
is difficult to control the temperature completely

15 constant.

Thus, it is desirable, in order to provide
a highly reliable system with low cost, to use a
material having a coefficient of linear thermal
expansion close to that of the laser diode for the

20 mount substrate so as to reduce the influence of the
thermal stress on the laser diode as small as
possible.

In this embodiment, various mount
substrates were produced by using various materials

25 having different coefficients of linear thermal

expansion and evaluation was made about the influence of the thermal stress on the output characteristic of the laser at the time of the laser oscillation. The surface-emission laser diode used in the experiment

5   has the structure explained with reference to Figure 1 and the laser oscillation wavelength was 1.3μm. Further, a chip size of 5 mm x 10 mm (thickness 0.6 mm) was used in which 20 laser diodes were aligned with a pitch of 300μm. The size of the mount

10 substrate made was 10 mm x 20 mm (thickness 2 mm).

The result is shown in Table 5. In Table 5, $\bigcirc$ represents the sample in which a stable output was obtained in the operational environment of 0 - 70°C , while $\times$ represents the sample in which no stable

15 output was obtained and hence not suitable for practical use.

Table 5

material	linear thermal expansion coefficient	laser output
quartz glass	0.3×10^{-6}/K	$\times$
smicrystal	2×10^{-6}/K	$\times$
CVD diamond	2×10^{-6}/K	$\times$
Si	4×10^{-6}/K	$\bigcirc$
SiC	4×10^{-6}/K	$\bigcirc$
AlN	5×10^{-6}/K	$\bigcirc$

GaAs	6×10^{-6}/K	○
Al-Si(60Al-40Si)	15×10^{-6}/K	×
Cu	17×10^{-6}/K	×

The coefficient of linear thermal expansion
of the laser diode of this invention is 6×10^{-6}/K.
From the above results, it can be seen that the

5   thermal stress is reduced and a stable laser output
is obtained when the difference of the linear thermal
expansion coefficient between the laser diode and the
mount substrate within about 2×10^{-6}/K. Particularly,
the materials such as Si, SiC, GaAs, AlN are easily

10   available and are easily processed and handled for
the mount substrate.

Further, by choosing the heat radiating
member on which the mount substrate is mounted such
that the material of the heat radiating member has a

15   linear thermal expansion coefficient close to that of
the laser diode, the stress to the mount substrate is
minimized and the mechanical stress applied to the
laser diode is reduced as a result. Further, the
material constituting the heat radiation member is

20   required to have a high thermal conductivity.

In the present invention, various heat

radiating members are formed by using various materials having different linear thermal expansion coefficients and the effect of heat generated at the time of the laser oscillation on the laser output

5   characteristics is evaluated.

The laser diode used for the evaluation was the same as the one used in the evaluation of Table 5. In this experiment, an SiC substrate having the same size as in the previous experiments was used for the

10   mount substrate.

Table 6 shows the results, wherein O in Table 4 represents the sample in which a stable output was obtained in the operational environment of 0 - 70℃, while X represents the case in which no

15   stable output was obtained.

Table 6

material	thermal conductivity	laser output
SiO2	about 8W/mK	X
Al2O3	about 17W/mK	X
Cobar	about 17W/mK	X
AlN	about 200W/mK	O
Cu/W	180 - 200W/mK	O
W	about 170W/mK	O
Mo	about 160W/mK	O
Cu	about 390W/mK	O

The thermal conductivity of the laser diode
of this invention is 55W/mK. Thus, from the results
noted above, it can be seen that a preferable result

5   is obtained when the thermal conductivity of the heat
radiating member is larger than the thermal
conductivity of the laser diode. Thus, the heat
generated at the time of the laser oscillation is
transferred to the mount substrate and then to the

10   heat radiation member without returning to the laser
diode when the thermal conductivity of heat radiating
member is larger than the thermal conductivity of the
laser diode of this invention. Thus, the output
fluctuation of the laser accompanied by the effect of

15   heat accumulation does not result and a stable
characteristic suitable for practical use is obtained.
Particularly, the materials such as AlN, Cu/W, W, Mo,
Cu are easily available and can be processed easily
to form a heat radiating member.

20   Especially the use of Cu/W is advantageous
as it allows control of the thermal conductivity by
controlling the compositional ratio and can be used
as a he package substrate to be explained later with
reference to Figure 79.

25   Hereinafter, an optical telecommunication

system of the present embodiment that uses such a member will be explained.

The telecommunication system is composed of the optical fiber or optical waveguide that operates as the transmission path between the photodetection part including a surface photodetection device and a driver circuit thereof and the optical transmission part including a surface-emission laser diode and a driver circuit.

The driver circuit of the laser diode or the photodetector is formed on the same mount substrate commonly with the laser diode of the photodetector to which the drive circuit cooperates, Alternatively, the driver circuit is formed on the laser diode substrate by a wafer process simultaneously to the process of forming the respective devices to which the driver circuit cooperates. Further, the optical telecommunication system performs the bi-direction telecommunication by providing the optical transmission part and the photodetection part at both ends of the optical transmission path.

Figure 78 shows an example of the optical transmission part of such an optical telecommunication system. In the drawing, those parts

explained previously are designated by the same reference numerals and the description thereof will be omitted.

Figure 78 is referred to.

5   The optical transmission part includes the surface-emission laser diode chip 32 and a driver circuit 32DR driving the laser diode chip 32, a mount substrate 131 on which the laser diode chip 32 and the driver circuit 32DR are mounted, a heat radiation

10 member 132 adjustably supporting the mount substrate 131 and for radiation of the heat, and a metal package 133 holding the heat radiation member 132 and acting as the heat sink or heat radiation fin, and an optical transmission 134 acting as the optical path.

15 The metal package 133 and heat radiation member 132 and also mount substrate 131 are connected mechanically and thermally with each other by a solder or a resin. Also, the laser diode 32 and the driver circuit 32DR are connected electrically by

20 wire bonding, and the like.

For example, the laser diode chip 32 includes the laser diode of Figure 1, wherein the laser diode may be the one that oscillates at the wavelength of 1.2μm. As for the mount substrate 131,

25 on the other hand, a Si substrate having the the

coefficient of linear thermal expansion of 4×10^{-6}/K
can be used. In this case, the laser diode 32 is die-
bonded with an AuSn solder on the mount substrate 131.
Thereby, electrode and electric mechanical connection
5 are achieved.

      It should be noted that an SiO_2 film 200nm
thickness is formed on the surface of the Si
substrate 131. This SiO_2 film may be formed by a
thermal oxidation process or a CVD process or an SOG
10 process. The foregoing oxide film is used for
insulation, but the heat radiation characteristic of
such a film is inferior to Si. Therefore, it is
preferable that the insulation film has as small
thickness as possible within the range of providing
15 sufficient electric insulation. The oxide film may be
omitted if it is possible. The driver circuit 32DR
that drives the laser diode chip 32 is mounted on the
same mount substrate 131 together with the laser
diode chip 32. A thermal conductive AlN substrate
20 (coefficient of linear thermal expansion 5×10^{-6}/K,
thermal conductivity 200W/mK) may be used as the heat
radiating substrate that carries the mount substrate.
The AlN substrate has excellent compatibility with
regard to the coefficient of linear thermal expansion.
25 Further, a powder mold product of Cu/W may be used

for the metal package 133. For example, the molded of

Cu/W product forming the metal package 133 may have

the composition of 89W-11Cu and a linear thermal

expansion coefficient of 6.5×10^{-6}/K and a thermal

5   conductivity of 180W/mK. By using such a powder mold

product, a highly precision product is obtained with

low cost. Further, it is possible to form heat

radiation fins easily and efficient heat radiation

becomes possible.

10   In the example of Figure 78, a multiple

mode optical fiber having a core diameter of 50μm is

connected optically as the optical fiber 134 with the

laser diode 32A in the laser diode chip 32. The

stability of such an optical telecommunication system

15   was evaluated in the operational environment of 0 -

70℃ from and it was confirmed that the laser output

is stable. No change of output characteristics was

observed. Further, there was no lifetime degradation.

Thus, it was found that an excellent optical

20   telecommunication system can be constructed.

            Furthermore, It is possible to use a GaAs

(coefficient of linear thermal expansion 6×10^{-6}/K) or

AlN (coefficient of linear thermal expansion 5×10^{-6}/K) or SiC (coefficient of linear thermal expansion

25   4×10^{-6}/K) for the substrate as the mount substrate

133 instead of the Si substrate. Because these substrates are an insulating substrate, formation of oxide film is not necessary when these substrates are used. Otherwise, the same structure may be used. In view of the cost and easiness of handling, the use of AlN is most preferable.

Also, good results were obtained when Cu/W (coefficient of linear thermal expansion is 6 - 8 x 10^{-6}/K, thermal conductivity is 180 - 200W/mK) such as 89W-11Cu, 85W-15Cu or 80W-20Cu, or the metals of W, Mo, Cu are used for the heat radiation member in place of AlN.

In the example of Figure 78, it was explained based on the construction that there is only one laser diode in the laser diode chip 32 forming the transmission part. However, it is possible to form an array of plural laser diodes also in the laser diode chip 32 or, by forming the array of the laser diode chip 32. Thereby, a large capacity optical telecommunication system is constructed.

For example, in the case of the multiple laser array chip in which plural laser diodes 32A are formed on a single chip 32, the laser diodes 32A come close with each other and the fluctuation of the laser output characteristic may be influenced by the

thermal stress caused by the heat generation and accumulation of the heat thus generated. Furthermore the laser diode driver circuit 32DR is often formed also on such a chip. Thus, the heat from such a

5   driver circuit 32DR is superimposed. In this embodiment, the laser output that stabilized without bringing about such a problem by choosing the material of the mount substrate 131 or the heat generation part 132 appropriately.

10   Formerly, the surface-emission laser diode having the oscillation wavelength of 1.1 - 1.7 microns did not exist. Therefore, the technological problems with regard to the optical telecommunication system or mounting of the surface-emission laser

15   diode chip of such a long-wavelength band have not been announced. This time, the inventor of this invention recognized the concrete technological problems for the first time by this invention and provided the resolution.

20   In the explanation above, a multimode optical fiber was used for the optical transmission path coupled optically to the laser diode chip 32. However, the optical transmission path may also be a single mode optical fiber or a plastic optical fiber.

25   The laser diode of the present invention does not

need expensive cooling device such as a Peltier device. But the present invention does not exclude the use do such a cooling device.

Next, another embodiment of the present invention will be explained with reference to Figure 79, wherein those parts corresponding to the parts described previously are designated by the same reference numerals and the description thereof will be omitted.

Referring to Figure 62, the present embodiment also shows the optical transmission part of the optical telecommunication system. In the present embodiment, the heat radiating member 132 functions also as the metal package 133.

It should be noted that the illustrated optical transmission part includes the laser diode chip 32 in which a number of laser diodes 32A are arranged in the form of laser array, the driver circuit 32DR driving the laser diodes 32A, a mount substrate on which the laser diode chip 32 and the driver circuit 32DR are mounted, a metal package 133 supporting the mount substrate 131 and functioning as the heat sink and also a heat radiating fin, an optical fiber 134 constituting the optical transmission path, and a ferule fixing the optical

fiber 134. A solder or a resin connects the metal

package 133 and the mount substrate 131 mechanically

and thermally. Further, the laser diode chip 32 and

the driver circuit (not shown) are connected

5 electrically by using a bonding wire.

In the illustrated example, the laser diode

of Figure 27 having the oscillation wavelength of 1.3

μm is used, and four devices are arranged with a

pitch of 250 μm, which is the pitch identical with

10 the pitch of the corresponding optical fibers.

Similarly to the previous embodiments, a Si substrate

was used for the mount substrate and the laser diode

was die bonded on the mount substrate by using an

AuSn solder. Further, the electrodes are connected

15 mechanically and electrically.

It should be noted that the surface of the

Si substrate is formed with an SiO2 film having a

thickness of 200 nm by a thermal oxidation process.

However, such an oxide film may be formed by a CVD

20 process or an SOG process. Further, in view of the

heat radiating performance of the SiO_2 film, it is

preferable to form the SiO2 film with a thickness as

small as possible. The SiO2 film may be omitted if it

is possible. Similarly, the driver circuit (not shon)

25 that drives the laser diode is formed also on the

common mount substrate.

As the metal package supporting the mount substrate and acting also as the heat radiating member, a powder mold product of Cu/W is used. For
5   example, the molded of Cu/W product forming the metal package may have the composition of 89W-11Cu and a linear thermal expansion coefficient of 6.5×10^{-6}/K, which is close to the linear thermal expansion coefficient of the laser diode. Further, the metal
10   package has a thermal conductivity of 180W/mK. By using such a powder mold product, a highly precision product is obtained with low cost. Further, it is possible to form heat radiation fins easily and efficient heat radiation becomes possible.

15   In the present embodiment, an array of multimode optical fibers in which the optical fibers each having a core diameter of 50μm are arranged with a pitch of 250μm is used. In the temperature range of 0 - 70℃, there occurs no change of laser
20   output and no lifetime degradation. Thus, excellent optical telecommunication becomes possible. As the metal package functions also as the heat radiating member, the number of parts can be reduced and the efficiency of heat radiation is maximized.

25   A similar result is obtained also when a

GaAs substrate or AlN substrate is used in place of the Si substrate. In the case of the AlN substrate or SiC substrate, they are insulating substrates and the formation of the oxide film is not necessary.

5   Otherwise, the foregoing description applies and further explanation will be omitted.

In the present embodiment, four laser diodes and four optical fibers are used. However, the present invention is by no means limited to this

10   specific construction but the present invention is applicable also to the case in which the number of the laser diode is one and the number of the optical fiber is one, or the number of the laser diodes is 8, 12, 16 and there are 8, 12, 16 optical fibers in

15   correspondence thereto.

In the case of the multi-laser diode array chip in which a plurality of laser diodes are formed on a common chip by exploiting the feature of the surface-emission laser diode of the present invention,

20   a large number of laser diodes can be formed easily and is ideal for large capacity telecommunication. On the other hand, in the case of such a multi-laser array chip, heat dissipation of the laser diodes becomes an important issue. By using the material of

25   the mount substrate and the heat radiating member as

set forth in the present embodiment, it becomes
possible to operate the laser diode array without
causing problems. Thereby, a stable laser output can
be obtained.

5   In the present embodiment, a multimode
optical fiber was used also for the optical
transmission path. However, this is not a mandatory
condition and it is possible to use an optical
waveguide, single mode optical fiber, plastic optical
10 fiber, and the like.

[FOURTEENTH EMBODIMENT]

            Next a telecommunication system according
to another embodiment of the present invention that
15 uses the long-wavelength surface-emission laser diode
of the present invention will be explained with
reference to Figure 80. In Figure 80, those parts
corresponding to the parts described previously are
designated by the same reference numerals and the
20 description thereof will be omitted.

            Referring to Figure 80, the
telecommunication system that uses the long-
wavelength surface-emission layer diode includes a
laser diode module 141 carrying thereon the laser
25 diode chip 32, a ferule 142A fixing the optical fiber

142, an adapter housing 143 accommodating the ferule 142A together with the optical fiber 142, a bush 144 fixing the optical fiber 142, a housing 145 accommodating the bush 144, and the base 146 that

5   holds the laser module 141 and the housing 143 as an integral body. In the construction of Figure 63, the length of the optical fiber 142 from the point A to the point B is set longer than the distance L (fixed distance) between the end surface of the adapter

10   housing 143 at the side of the laser diode chip 32 and the end surface of the housing 145.

More particularly, in the case the fixed length L is set to 1 in Figure 80, the length A-B of the optical fiber 142 is set to 1.05. Thereby, the

15   optical fiber 142 is provided with a bend, and the resilience associated with the bend causes the optical fiber 142 to be urged in the axial direction toward the optical emission part 32A (left direction in the drawing). Thereby, the mechanical connection

20   is stabilized and an excellent optical coupling can be realized. Here, a plastic optical fiber is used as the optical fiber 142 but the present invention is by no means limited to such a specific case and it is possible to use a quartz glass fiber having a plastic

25   coating.

Figure 81 shows the case in which the length L of Figure 80 is set to 1 and the length A-B of the optical fiber is set to 2. Other conditions are identical with the case of Figure 80. In the present embodiment, a larger resilient force is obtained as compared with the case of Figure 80 and the connection between the laser diode and the optical fiber becomes more reliable.

Figure 82 shows the cross-sectional view of the adapter housing 143 used in the optical telecommunication system of Figure 80 or 81.

Referring to Figure 82, the adapter housing 143 includes a tapered split sleeve 1431, a ferule 142A fixing the optical fiber 142, a coil spring 1432 of a shape-memory alloy exerting a force in the axial direction, a collar 1433 cooperating with the coil spring 1432 and a plug housing 1434 accommodating therein the split sleeve 1431, the coil spring 1432 and the collar 1433, and a connecting member 1435 for connecting the plug housing 1434 to the adapter housing 143.

The coil spring 1432 exerts a resilient force at the ordinary temperature or heated state determined by the initial shape. Thus, with cooling, the coil spring may extend and urge the ferule 142A

in the axial direction thereof. Depending on the
design of the connecting member 1435, it is possible
to memorize the shape such the coil spring 1432
extends at the high temperature side.

5   Figure 83 shows a modification of Figure 82,
wherein those parts corresponding to the parts
described previously are designated by the same
reference numerals and the description thereof will
be omitted.

10   Referring to Figure 83, the coil spring
1432 of the shape-memory alloy is replaced with a
leaf spring 1432A of a shape-memory alloy and the
leaf spring exerts a resilient force at the ordinary
temperature or at the heated state determined by the
15 initial shape of the spring. Thus, the leaf spring
1432A may extend with cooling and urge the optical
fiber 142 in the axial direction thereof. Depending
on the design of the connecting member 1435, the leaf
spring 1432A may extend at the high temperature side.

20   It should be noted that the spring 1432 or
1432A is not limited to a shape-memory alloy but may
be formed of a shape-memory plastic. In such a
connection module, there exists a temperature
difference between the temperature in which the
25 optical telecommunication system is assembled

(generally higher than the room temperature) and the temperature (room temperature) in which the system is used. Because of this temperature difference, the shape-memory material changes the shape thereof and

5   generates a resilient force in the state that the member is assembled in a structural body. It should be noted that the sense of temperature change (between the state in which the system is assembled and the state in which the system is used) may be

10   reversed.

Figure 84 shows another example of the telecommunication system that uses the long-wavelength laser diode according to the present invention, wherein those parts corresponding to the

15   parts described previously are designated by the same reference numerals and the description thereof will be omitted.

Referring to Figure 84, the telecommunication system of the present embodiment is

20   formed of a laser module 141 carrying the laser diode chip 32, a ferule 142A for fixing the optical fiber 142, an adapter housing 143 accommodating the ferule 142A therein together with the optical fiber 142, a fixing apparatus 147 holding and fixing a part of the

25   optical fiber 142, and abase 146 fixing the adapter

housing 143 and the fixing apparatus 147 and the laser module 141 as an integral body. Thereby, the telecommunication system of Figure 67 provides a bend to the optical fiber 142 between the adapter housing

5 143 and the optical fiber fixing apparatus 147.

The optical fiber fixing apparatus 147 is a device that uses a frictional grip compression and includes a shape-memory alloy compressional spring 1471, a collar 1472 cooperating with the spring 1471,

10 another collar 1473, a ball 1474 disposed between the collars 1472 and 1473, and a housing 1475 having a conical surface in contact with the ball 1474. In the housing 1475, the ferule 142B holding the optical fiber 142 and the split sleeve 1476 are accommodated

15 in the state that the shape-memory alloy spring 1471 intervenes between the collar 1472 and the split sleeve 1476.

In the optical telecommunication system of such a construction, the fiber 142 urges a force

20 acting in the left and right directions upon thermal deformation, while such an urging force pushes the ball 1474 in the optical fiber fixing apparatus 147 in the right direction by the action of the compressional spring 1471. Thus, the optical fiber

25 142 cannot move in the right direction and exerts a

force to the side of the adapter housing at the
opposite side.

In the example of Figure 63, the optical
fiber 142 is provided with a bend and the optical
5   fiber 142 urges the optical fiber 142 in the
direction of the laser diode chip 32 as a result of
the resilient force associated with the bend of the
optical fiber 142. In the example of Figure 84, the
resilient force of the optical fiber 142 is boosted
10   with the superimposed resilient force of the spring
147 of the shape memory alloy, and the optical fiber
142 is urged more effectively to the direction of the
laser diode chip 32.

Figure 85 shows the optical connector
15   formed of the tapered split sleeve 1431, the ferule
142A holding the optical fiber 142, the coil spring
1432 applying an axial urging force to the ferule
142A, the collar 1433, a plug housing 1434
accommodating therein the split sleeve 1431, the coil
20   spring 1432 and the collar 1433, and the adapter
housing accommodating the ferule 142B and the plug
housing 147, wherein the optical connector having
such a construction is connected with another optical
connector by connecting the respective connector
25   housings 143with each other by way of a connecting

screw 1436.

In the construction of Figure 65, it should be noted that the coil spring 1432 exerts an urging force at the normal temperature as a result of the initial shape thereof. Thus, the coil spring 1432 is extended at the normal temperature change, and the ferule 142A is urged in the direction of the axis of the optical fiber 142. Thereby, two optical fibers are connected effectively. In this example, too, it is possible to use various shape memory alloys and shape memory plastics. In the example noted above, the present invention was explained with reference to the example that uses a shape-memory alloy for the spring. However, it is possible to use an ordinary resilient material such as copper bronze or urethane foam. By using such well-known art, it is possible to reduce the cost of the module.

[Fifteenth Embodiment]

Next, a further embodiment of the present invention will be explained.

Figure 86 shows an example of the construction of the optical transmission part that is provided with the optical telecommunication system that uses the surface-emission laser diode of the

present invention. In Figure 86, those parts

explained previously are designated by the same

reference numerals and the description thereof will

be omitted.

5   Figure 86 is referred to.

In the present embodiment, a connector

substrate 151 holding plural optical fibers 142 on

the mount substrate 131 is provided such that each of

the plural surface-emission laser diodes 32 forming a

10   part of the array opposes with a corresponding one

the plural optical fibers 142. Further, plural

photodetection devices 142P are provided on the

connector substrate 151 so as to monitor the optical

power of the surface-emission laser diodes 32, such

15   that the photodetection devices 142P correspond

respectively to the plural optical fibers 142. Each

of the photodetection device 142P is provided as it

face the corresponding surface-emission laser diode

32 for detecting the optical beam emitted therefrom.

20   In Figure 86, it can be seen that the laser

diode chips 32, the optical fibers 142 and the

monitoring photodetectors 142P are arranged to form a

one-dimensional array. However, a similar effect is

achieved also when the photodetectors 142P are

25   disposed in a two-dimensional array. In this drawing,

each of the laser diodes is represented as an independent chip 32. However, the laser diodes may be the one formed on a common chip 32.

In Figure 86, illustration of the driver
5   circuit of the surface-emission laser diode 32 or the laser output control circuit for feedback control of the laser output based on the signals acquired from the driver circuit or monitoring photodetection device is omitted for the sake of simplicity.

10   In the example of Figure 86, the connector substrate 151 holds the optical fiber 142 and is mounted on the mount substrate 131 by using a connector guide 151A.

Each of the optical fibers is held in a
15   penetrating hole provided in the connector substrate surface 151 so that the end surface of the optical fiber faces a corresponding laser diode element 32A in the laser diode chip 32. Further, each laser diode elements 32A and the corresponding optical fiber 142
20   are aligned optically. Further, there is provided a monitoring photodetector 142P in the vicinity of the optical fiber insertion hole of the connector substrate 151.

Here, the majority of the laser beam
25   emitted from the surface-emission laser diode is

injected into the optical fiber 142 aligned to the
laser diode. On the other hand, the part of the laser
beam failed to enter the optical fiber 142 is
detected by the photodetection device 142P.

5   Figure 87 shows the block diagram of the
control system that stabilizes the output of the
surface-emission laser diode 32 by using the
monitoring photodetector 142P shown in Figure 86.
           Referring to Figure 87, the surface-
10   emission laser diode 32 is driven by a laser drive
circuit 161 to which the data signal (electrical
signal) is supplied, and there is formed a laser bean
as a result. A part of the laser beam thus formed is
detected as the leakage light, and the output
15   electrical signal of the photodetector 142P is
supplied to a feedback control circuit 162. The
feedback control circuit 162 in turn controls the
laser driver circuit 161 so as to compensate for the
change of the output electrical signal of the
20   photodetection device 142.

           It should be noted that no strong optical
power is needed for the laser beam detected by the
monitoring photodetector 142P, as the monitoring
photodetector merely detects the change of the laser
25   output for feedback control. From the viewpoint of

long range optical telecommunication, it is
preferable that most of the optical power is injected
into the optical fiber, while the system of using the
feeble leakage light at the incident end of the
5   optical fiber 142 is sufficiently practical.

Figure 88 shows another embodiment of the
present invention.

Referring to Figure 88, the monitoring
photodetector 142P is formed between the surface
10   emission laser diode chip 32 and the connector
substrate 151 in the vicinity of the incident end of
the optical fiber 142 facing the laser diode chip 32.
Similar to Figure 86, the laser diodes 32, the
optical fibers 142 and the photodetection devices
15   142P are arranged in a one-dimensional array, while
the present invention is not limited to such a
specific case but is applicable also to the case in
which there is formed a two-dimensional array on the
mount substrate 131. Similarly to the explanation
20   above, each of the laser diodes is represented as a
chip, while it is also possible to form a number of
laser diode emission parts 32A on a single chip 32
monolithically as a laser diode element. In view of
simplicity of illustration, the driver circuit and
25   the laser output control circuit are not illustrated.

In the example of Figure 88, the monitoring
photodetector 142P is provided between the substrate
131 and the connector substrate 151 in the form
supported on a support member 142W, contrary to the
5 case of Figure 86.

Figure 89 shows a further embodiment of the
present invention.

Referring to Figure 89, the monitoring
photodetectors 142P are disposed on the mount
10 substrate 131 together with the surface-emission
laser diode chip 32 and detects a part of the optical
beam reflected by the connector substrate 131. In
this embodiment, too, it is possible to form a number
of laser diode elements 32A in a laser diode chip 32
15 and form the photodetectors 142P also on the chip 32
monolithically adjacent to the laser diode elements
142P.

According to the latter construction, the
laser diode elements 32A and the photodetectors 142P
20 are formed simultaneously and with high precision.
Further, the cost of assembling is reduced. In Figure
89, too, the illustration of the driver circuit of
the laser diode 32 or the output control circuit is
omitted for the sake of simplicity.

25 In the present embodiment, most of the

laser beam emitted from the surface-emission laser
diode 32 is injected into the optical fiber 142
coupled optically to the laser diode 32. Thereby, the
part of the laser beam failed to enter the optical

5   fiber 142 is reflected at the bottom surface of the
connector substrate and enters the photodetection
device 142P. Thus, in the present embodiment, too, it
is possible to control the output of the laser diode
32 by using the leakage light at the incident end of

10 the optical fiber 142.

Next, another embodiment of the present
invention will be described with reference to Figure
90.

Referring to Figure 90, it can be seen that

15 the relationship between the laser diode 32 and the
monitoring photodetector 142P is the same as in the
case of Figure 89 except that there is provided a
reflector 151R at the bottom surface of the connector
substrate 151 for improving the efficiency of

20 reflection.

Such a reflector 151R can be formed by
providing a metal film of Al, Ag or Au on the bottom
surface of the connector substrate 151 that faces the
laser diode 32. In order to reflect the optical beam

25 of long wavelength, it is preferable to use a metal

film of Au.

In the present embodiment, too, it is possible to control the laser output of the surface-emission laser diode by using a leakage light which has failed to enter the optical fiber in the vicinity of the optical fiber, similarly to the previous embodiments. As a result of the use of reflector, the optical output control is achieved with improved precision with weaker power of the reflection light.

[SIXTEENTH EMBODIMENT]

Next, a further embodiment will be described.

Figure 91 shows an example of the optical telecommunication system that uses a long-wavelength laser diode of the present invention. More specifically, Figure 91shows the construction in which the optical fiber 72 extending out from the module package 71, in which the laser diode chip 32 is accommodated, is connected to the optical fiber 73 of the optical telecommunication system. In Figure 91,those parts corresponding to the parts described previously are designated by the same reference numerals and the description thereof will be omitted.

Referring to Figure 74, the optical fiber

72 drawn out from the module package 71 is connected
to the optical fiber 73 used for optical
telecommunication at the optical connector 171. When
there exists air at the connection part, there arises

5   a reflection of the optical beam in view of the
difference of refractive index of the air with
respect to the refractive index of the optical fiber
72 or 73. In order to suppress such a fluctuation of
refractive index a the optical fiber connection part,

10   there are proposals to inject a refractive index
matcher in the form of a gel so as to suppress the
fluctuation of the refractive index or to achieve a
complete attachment of the optical fibers (PC:
physical contact). The present invention uses this PC

15   technology for the connection of the optical fibers.

As represented in Figure 91, the optical
fibers 72 and the optical fibers 73 are held in the
connector 171 respectively by a ferule 72F and a
ferule 73F for preventing damaging of the optical

20   fibers. The ferules 72F and 73F are formed of a
cylindrical body of a zirconia ceramic that has a
large mechanical strength. Thereby, the optical
fibers are inserted into the central hollow part, and
fixed therein by using an adhesive. Further, the

25   ferules 72F and 73F are held in the optical connector

171 by a pair of split sleeves 172.

Figure 92 shows the relationship between the optical fibers 72 and 73, the ferules 72F and 73F and the split sleeve 172.

5　　　　Referring to Figure 92, the split sleeve 172 consists of a pair of members formed of a copper bronze and having the shape of being split from a hollow cylinder.

As represented in Figure 92, a pair of

10　split sleeve members 172 holds the ferules 72F and 73F, and the ferules 72F and 73F are urged with each other by respective springs 173A and 173B with a predetermined force. Thereby, there is formed the desired PC connection. In the present embodiment, it

15　is possible to construct a rigid and highly reliable optical connection.

Generally, a laser diode is provided with a safety standard for preventing damages to human body. In the case of the surface-emission laser diode of

20　$1.1 - 1.7 \mu m$, it is possible to satisfy the safety standard while operating the laser diode with a large output power as compared with the laser diode having the oscillation wavelength in the visible wavelength band $(0.4 - 0.7 \mu m)$.

25

[SEVENTEENTH EMBODIMENT]

Next, another feature of the present invention will be described of the coupling between the laser diode and optical fiber or laser diode and optical waveguide.

As represented in Figure 93, the laser beam of the surface emission laser diode emitted perpendicularly to the substrate has a optical intensity distribution generally close the Gauss distribution profile in the plane perpendicular to the optical axis.

Assuming that the beam diameter is equal to the FWHM (full-width half-height) value of the beam profile, it is possible to evaluate the emission angle θ of the optical beam from the beam diameter and the distance between the laser diode and the detection surface.

As a result, it turned out that the emission angle θ of the surface-emission laser diode of the present invention is generally symmetric about the optical axis and takes a value of 5 - 10degrees.

In contrast to this, conventional laser diode of the edge-emission type having the same oscillation wavelength of 1.1 - 1.7 μm has a much larger emission angle θ and a very large aspect

ratio. Typically, the optical emission angle $\theta \perp$ has
a value of about 35 degrees in the direction vertical
to the plane of the substrate and the optical
emission angle $\theta //$ parallel to the place of the
5   substrate takes the value of about 25 degrees. Thus,
it has been necessary to use an optical element such
as a microlens for realizing high efficiency optical
coupling.

       In contrast to this, in the case of the
10   surface-emission laser diode of the present invention,
the angle of optical emission θ is very small as
noted above, and the spreading of the optical beam is
minimized even in the case there is a large distance
between the laser diode and the optical fiber or
15   between the laser diode and the optical waveguide.
Thereby, it becomes possible to eliminate the
microlens, while the removal of the microlens
provides an beneficial effect in that the distance
between the laser diode and the optical fiber is
20   reduced. Further, even in the case the distance
between the laser diode and the optical fiber or the
laser diode and the optical waveguide is large, the
spreading of the optical beam is small and an
efficient optical coupling becomes possible without
25   providing an intervening lens.

Figure 94 shows a schematic diagram with regard to spreading of the laser bean in the laser diode 32 of the present invention and Figure 95 shows an example of calculation of beam spreading.

5   Referring to Figure 94, the laser emission part 32A of the laser diode 32 has an aperture size d [μm] and the laser beam is emitted from the laser emission part 32A with an emission angle θ. Further, there is provided an edge surface of the optical beam

10   180 at the position separated from the laser diode 32 with an optical length 1 [μm]. The optical fiber 180 includes a core 181 having a diameter X [μm] and a cladding 182 surrounding the core, and the optical fiber 180 is provided so as to align the laser diode

15   optically such that the optical axis of the optical fiber 180 and the optical axis of the laser diode coincide with each other. Here, it should be noted that the diameter d of the aperture represents the diameter itself when the diameter has a circular

20   shape, while in the case the diameter has a square shape, the diameter d represents the length of one edge. Further, when the opening has other shape such as a rectangle, the diameter d represents the diameter of a circle having an area of an ellipse

25   inscribing the rectangular opening.

The reason that the optical path length between the laser diode and the optical fiber edge or optical waveguide edge is to include the case of using a mirror for deflecting the optical beam to be

5   described later with reference to Figure 97. When there is no such a deflection of the optical path and the optical beam propagates straight, the optical path length from the laser diode to the optical fiber edge or the optical waveguide edge becomes identical

10 with the distance from the laser diode to the optical fiber edge or the optical waveguide edge. In the case of an optical waveguide, it is general that the core cross-section is not a circle but a square or rectangle. Thus, in the case of a square core, the

15 edge size is set as X [μm], while in the case of a rectangular core, the size of the shorter edge is defined as X [μm].

In Figure 94, it can be seen that the beam size of the optical beam emitted from the laser diode

20 perpendicularly to the epitaxial layers therein, the beam diameter of the laser beam increases with the optical path length L and the optical emission angle θ until it reaches the edge surface of the optical fiber or optical waveguide. Thereby, the beam size at

25 the optical fiber edge or the optical waveguide edge

is given as

$$d + 2l \tan(\theta/2).$$

Thus, when this beam size falls in the core diameter X of the optical fiber or the optical

5 waveguide, excellent optical coupling is achieved.

Based on the above equation, Figure 95 shows the relationship between the optical path length l and the beam diameter for the case of the aperture diameter of 5μm and the optical emission

10 angle of 10 degrees, in comparison with the conventional case of an edge-emission type laser diode having an optical emission angle of 35 degrees.

Referring to Figure 95, it can be seen that the spreading of the beam diameter is substantially

15 small as compared with the conventional case and that it is possible to coincide the core diameter X and the beam diameter in the case a commonly used multimode optical fiber having a core diameter of 50 μm (cladding diameter of 125μm) is used for the

20 optical fiber, provided that the optical path length l is set to 260μm.

As long as the optical path length l is smaller than the foregoing length in which the core diameter X coincide with the beam diameter, it is

25 possible to achieve an excellent optical coupling

with little optical loss. From the result of Figure
95, it is concluded that the optical alignment
between the laser diode and the optical fiber or
optical waveguide is not critical in the axial
5   direction in the case of the laser diode of the
present invention, and a very coarse alignment is
sufficient for achieving the necessary optical
coupling. In the case of a plastic optical fiber
having a core diameter of 100μm is used, the optical
10   path length 1 in which the laser beam diameter
coincides with the core diameter increases further to
550μm. Thereby, it is possible to provide the
optical fiber with a separation from the laser diode
package.

15   Figure 96 shows an example of coupling an
optical fiber of an optical telecommunication system
with the surface-emission laser diode of the present
invention. In Figure 96, those parts corresponding to
the parts described previously are designated by the
20   same reference numerals and the description thereof
will be omitted.

           Referring to Figure 96, the
telecommunication system includes the mount substrate
131 carrying thereon the surface-emission laser diode
25   chip 32 in which the laser diodes 32A are formed as a

two-dimensional array, and the mount substrate 131
further carriers a driver circuit of the laser diode
not illustrated. Further, there are provided a two-
dimensional array of photodetectors (not shown) as
5   well as the driver circuit not illustrated
cooperating with the photodetectors, wherein an
optical fiber array including optical fibers 191 is
provided on the laser diode chip 32 such that each of
the optical fibers 191 face a corresponding laser
10   diode 32A. It is also possible to use an optical
waveguide array in place of the optical fiber array
in the construction of Figure 96. Further, the
optical telecommunication system of Figure 96 may be
a bi-directional optical telecommunication system. In
15   this case, the optical transmission part and
photodetection part are provided at both ends of the
optical fibers.

Referring to Figure 96, the mount substrate
131 is formed of a thermally conductive Si substrate
20   and the laser array chip 32 is mounted on the mount
substrate 131. The laser array chip 32 may contain
the laser diode of Figure 1 as a laser diode element
constituting the array. In the illustrated example,
the laser diodes having an oscillation wavelength of
25   1.3 μm is used, wherein each of the laser diodes 32A

has an aperture having the diameter of $10\,\mu$m for optical output. Twelve laser diodes 32A are formed on the mount substrate 131 with a pitch of $200\,\mu$m.

On the mount substrate 131, there is

5 provided a hole array member 191 having a number of penetrating holes with a pitch of $200\,\mu$m in correspondence to the pitch of the laser diodes 32A on the chip 32, wherein each of the holes has a diameter of $125\,\mu$m in correspondence to the diameter

10 of the multimode optical fibers. The hole array member 191 may be formed of AlN and carries a guide 191X in correspondence to a marker 32X provided on the laser diode chip 32. Thereby, the hole array member 191 is mounted on the laser diode chip 32 such

15 that the guide 191X coincides with the marker 32X. The hole array member 191 has an excellent thermal conductivity of about 300 $Wm^{-1}K^{-1}$ and is used as an effective heat radiation part when it is provide close to the laser diode chip 32. Thereby, a stable

20 optical telecommunication system is realized by dissipating the heat associated with the laser oscillation efficiently.

In each of the penetrating holes of the hole array member 191, a multimode optical fiber 192

25 is inserted and the optical fiber is fixed therein by

an adhesive in the state that the optical fiber
engages the laser diode chip 32. With such a
construction, it is possible to achieve an exact
alignment between the laser diode element 32A and the

5 optical fiber 1691 in the direction perpendicular to
the optical axis direction.

As noted above, the optical fiber 191 is
merely contacted with the chip 32 and the accuracy of
optical alignment in the axial direction is poor.

10 There can be a case in which a space of 0 - 20μm may
be formed between the laser diode and the optical
fiber. However, because of the very small emission
angle θ of the laser diode of 8 degrees in the
present example, and in view of the large diameter d

15 of 10μm for the laser diode 32A, the optical beam
diameter is only 17μm at the distance of 50μm from
the surface of the laser diode chip 32. Thus, the
beam diameter is still much smaller than the core
diameter of 50μm for the multimode optical fiber 192,

20 and excellent optical coupling is maintained. Further,
there is no need of providing a coupling lens between
the laser diode 32A and the optical fiber 191.

In the experiment conducted on the
construction of Figure 96 in which the optical fiber

25 191 is pulled out gradually after being contacted

with the laser diode chip 32 by using a micrometer,
it was confirmed that the laser diameter becomes 66μ
m when the distance between the laser diode and the
optical fiber is 66μm. In this case, the optical

5   beam diameter is larger than the core diameter of the
multimode optical fiber 191 and the foregoing
relationship is failed. Thus, no sufficient optical
coupling would be achieved in this case.

Table 7 below represents the experiments

10   conducted by the inventor.

Table 7

d+21 tan(θ/2) [μm]	x (μm)	remarks
10	50	O
20	50	O
30	50	O
40	50	O
50	50	O
60	50	△
70	50	×
80	50	×
10	62.5	O
20	62.5	O
30	62.5	O
40	62.5	O

50	62.5	O
60	62.5	O
70	62.5	X
80	62.5	X

O   good optical coupling, sufficient for practical use

△   slightly degraded optical coupling, difficult for practical use

5   X   poor optical coupling, cannot be used for practical applications

From the result of above, it can be seen that a practical optical coupling cannot be achieved

10   unless the core diameter X is larger than the term given as $d + 2l \tan(\theta/2)$, where θ is the emission angle of the optical beam and l represents the optical path length from the laser diode to the optical fiber, d represents the diameter of the laser

15   diode opening.

In the explanation above, it should be noted that the number of the optical fibers is not limited to 12 but there may be only one optical fiber or there may be 4, 8, 16 optical fibers. Further, the

20   present invention is not limited to a multimode fiber 191b but a single mode optical fiber may also be used

for long distance transmission. Further, it is
possible to use a plastic optical fiber (POF), which
is advantageous to construct a short distance, low
const optical telecommunication system. In such a

5   system, it is preferable to provide an anti-
reflection coating on the edge surface of the optical
fiber. In the present embodiment, it is also possible
to use Si or C or alumina ceramics for the hole array
member 191. As the hole array member 191 functions

10 also as a heat radiation part, it is preferable to
use a material having a high thermal conductivity.

[Eighteenth Embodiment]

Next, another feature of the present

15 invention will be described of the coupling between
the laser diode and optical fiber or laser diode and
optical waveguide.

The construction of the present invention
is similar to that of Figure 96 except that the lser

20 diode chip 32 and the optical fiber are contacted
with each other and the distance between the laser
diode chip 32 and the optical fiber 191 or optical
waveguide is set to almost zero. Here, the
representation "contact" also includes a separation

25 of 0 - 10 μm by taking into consideration of the

error at the time of the assembling process.

In the present embodiment, a Si substrate having good thermal conductivity is used for the mount substrate 131 and the laser array chip 32

5 including an array of surface-emission laser diodes 32A is mounted on the mount substrate 131. The laser diode 32A used in the present embodiment has a laser oscillation length of $1.3 \mu m$.

In the present embodiment, the diameter of

10 the laser diode is set to $10 \mu m$ and 12 laser diodes 32A are formed with a pitch of $200 \mu m$.

Next, the multimode optical fibers 192 are inserted into the holes in the hole array member 191 having the penetrating holes of $125 \mu m$ diameter with

15 the corresponding pitch of $200 \mu m$. Thereby, the tip ends of the optical fibers 192 are projected slightly from the hole array member 191 such that the tip end of the optical fiber makes an engagement with the laser array chip 32.

20 Next, the tip end part of the optical fiber is polished, and the tip end of the optical fibers is aligned at the side of the hole array member 191 that makes a contact with the laser diode chip 32. After this, the marker X and the guide 191X are matched and

25 the optical alignment is achieved between each of the

laser diodes 32A and the corresponding optical fiber
192. The laser array chip 32 and the hole array
member 191 are then fixed in this state, and the
laser diode chip 32A and the optical fiber 192 are
5   coupled with each other.

        According to the present embodiment, an
optical coupling better than the previous embodiment
is achieved. Thus, in the present embodiment, there
occurs little spreading of the optical beam and the
10   laser beam diameter is more or less coincident with
the diameter d of the aperture forming the laser
diode 32A. Thus, the diameter of the laser beam is
sufficiently smaller than the core diameter of the
optical fiber 191 and the alignment margin in the
15   axial direction is increased further. Thereby, it
becomes possible to construct an optical system using
a 1.3μm surface emission laser diode with low cost.

[NINETEENTH EMBODIMENT]
20   Figures 97A and 97B are diagrams showing
the coupling of the laser diode and an optical wave
guide according to another embodiment of the present
invention, wherein Figure 97A shows an oblique view
while Figure 97B shows a cross-sectional view.
25   In the present embodiment, the laser beam

emitted from a laser diode 32A is deflected by a mirror 301. In Figures 80A and 80B, those parts corresponding to the parts described previously are designated by the same reference numerals and the

5   description thereof will be omitted.

Referring to Figures 97A and 97B, a Si substrate having an excellent thermal conductivity is used for the mount substrate 131, and the laser array chip 32 in which the laser diodes 32A are arranged in

10   the form of an array is mounted on the mount substrate 131. In the present embodiment, each of the laser diodes 32A has an aperture with a diameter of $15\mu m$, and four laser diodes 32A are formed.

In this embodiment, another mount substrate

15   131A is provided in which a mirror 301 is formed by mounting a reflecting member or forming a reflecting layer monolithically. Further, an optical waveguide 302 is formed on the mount substrate 131A. For example, the mirror 301 may be formed by applying an

20   anisotropic etching to the Si substrate by using a KOH etchant and by providing an Ag film on the crystal surface formed as a result of the anisotropic etching.

In the present embodiment, an optical

25   waveguide 302 is formed on the mount substrate 131A.

The optical waveguide 302 is formed by depositing a lower cladding layer 302A, followed by depositing a polymethacrylate (PMMA), followed further with a patterning process to form a core pattern 302B.

5 Typically, the core pattern 302B has a cross sectional form of 50 x 50 μm. Other than PMMA, the optical waveguide layer may be formed also by polyimide or epoxy resin or polyurethane or polyethylene. Further, it is also possible to form an

10 inorganic film such as silicon oxide film. Further, these organic films may be formed by a spin-coating process of dip-coating process in combination with a patterning process. Further, it is possible to form the optical waveguide by a resin molding process or

15 molding process.

In the present embodiment, the mount substrate 131 and the mount substrate 131A carrying the optical waveguide 302 are fixed such that the optical axis of the laser diode 32A and the optical

20 axis of the optical waveguide 302 become coincident.

In the experiments conducted by the inventor, a laser diode having an aperture of 15 μm diameter and the optical emission angle θ of 10 degrees is used, and the optical path length l

25 between the laser diode 32A and the optical waveguide

302 is changed by setting the position of the end surface of the optical waveguide 302 to 50μm, 100μm and 250μm. As a result, it was confirmed that an excellent result is obtained in the case the optical

5 path length is 50μm and 100μm, while no satisfactory optical coupling was achieved in the case the optical path length is set to 250μm.

Anyway, the present embodiment can eliminate the lens and only a coarse optical

10 alignment is sufficient for the axial direction. Thus, by using a surface-emission laser diode of 1.2μm, it becomes possible to construct an optical alignment having a tolerance with regard to the optical alignment in the axial direction or the direction of

15 the optical axis.

In the present embodiment, the mirror 301 is formed separately to the optical waveguide 302. On the other hand, it is possible to form a 45degree surface at the end of the optical waveguide 302 by a

20 dicing blade, and the like, and by depositing a metal film such as Ag on such an oblique surface. Thereby, a mirror integral with the optical waveguide 302 is formed.

In the present embodiment, the diameter of

25 the optical waveguide is set to 50μm in

correspondence to core diameter of the multimode optical fiber. In the case a single mode optical fiber is used, the diameter of the optical waveguide has to be set to about 10μm. In this case, too, the

5   same fundamental equation holds. Further, it should be noted that the cross sectional form of the core pattern 302B in the optical waveguide 302 is not limited to the square pattern but a rectangular pattern may also be used. Further, it is possible to

10   transmit plural optical signals in a single optical waveguide as in the case of an optical sheet.

[TWENTIETH EMBODIMENTS]

Figure 98 shows the construction of

15   coupling the laser diode chip 32 with the optical waveguide 302 according to another embodiment of the present invention.

Referring to Figure 98, a Si substrate having excellent thermal conductivity is used for the

20   mount substrate 310 and the laser diode chip 32 carrying the laser diodes 32A of the structure of Figure 1 is mounted on the substrate 310. In the present embodiment, too, a surface-emission laser diode having an oscillation wavelength of 1.3μm is

25   used for the laser diode 32A. The laser diode used in

the preset embodiment has the aperture diameter d of

7μm and the optical emission angle θ of 8 degrees.

In the present embodiment, the laser diode 32A is

used as a single device, not in the form of array.

5   The mount substrate 310 carrying thereon

the laser diode chip 32 is fixed on a package body

311 with positioning. Further, the optical axis of

the laser diode 32 is aligned with the optical axis

of the single mode optical fiber 313 held on an

10 optical fiber guide 312, by aligning the optical

fiber guide 312 and the package 311 in advance by

using a guide 311A on the package body 311 and a

guide pin 312A on the optical guide 312.

      The single mode optical fiber 313 includes

15 a core 313A having a diameter of 10μm and a clad

having a diameter of 125μm and surrounding the core

313A, wherein the diameter of the optical fiber guide

312 is set so as to coincide with the outer diameter

of the cladding of the optical fiber 313.

20   In the construction of the present

embodiment, an excellent optical coupling is achieved

by contacting the single mode optical fiber 313 to

the laser diode 32. Further, the present invention

enables a broadband optical signal transmission by

25 using the single mode optical fiber 313 over a long

distance. Thus, according to the present embodiment,
it became possible to construct an optical
telecommunication system having excellent optical
coupling by using the surface-emission laser diode of

5   the 1.3 μm band.

[Twenty-first Embodiment]

        Next, another embodiment of the present
invention will be described.

10   Figure 99 shows an example of the optical
telecommunication system that uses a long-wavelength
laser diode according to another embodiment of the
present invention.

        Referring to Figure 99, the optical

15   transmission system includes a surface-emission laser
diode 32 having the emission part 32A and an optical
fiber 352, wherein the laser diode 351 and the
optical fiber 352 are coupled directly at the laser
emission part 32A. Of course, it is possible to

20   achieve the optical coupling by using a lens.

        Assuming that the laser emission part 32A
of the surface-mission laser diode 32 is d and the
core diameter of the optical fiber 312 as F, it can
be seen that the laser beam from the laser diode 32

25   diverges as represented in Figure 99 by a broken line

351B. In Figure 99, it should be noted that d
represents the diameter of the circle inscribing the
polygonal laser emission part 32A. In this case, the
emission angle of the laser beam is much smaller than
5   the case of a conventional edge-emission laser diode.
Thus, in the case the laser diode 32 is provided near
the optical fiber, it should be noted that a high
optical coupling can be achieved when the optical
axis of the laser diode is perpendicular to the
10   optical fiber end surface and is coincident with the
optical axis of the laser diode, and the aperture
diameter of the laser diode is equal to or smaller
than the core diameter.

As noted before, the surface-emission laser
15   diode used in the present embodiment operates in the
wavelength band of $1.1 - 1.7 \mu$m, and a long distance
transmission becomes possible by using the wavelength
band of $1.3- 1.55 \mu$m due to the small optical loss of
the quartz optical fiber in this wavelength band.

20   Assuming that the laser emission part 32A
of the laser diode 32 has the diameter of d (in the
case the laser emission part 32A has a polygonal
shape, the diameter d is the diameter of a circle
inscribing the polygonal laser emission part 32A, it
25   is possible to increase the optical coupling

efficiency by setting the foregoing parameters F and d so as to satisfy the relationship of

$$F/d \leqq 2 \qquad\qquad (2)$$

In the embodiment of Figure 99, it should

5   be noted that the laser emission part 32A and the optical fiber 352 are coupled directly and no lens is interposed.

In the conventional optical system that uses an edge emission type laser diode of the 1.3 μm

10   band, there is been a poor optical coupling efficiency between the laser diode and the optical fiber, and it has been difficult to couple these directly. Further, the return beam incident to the laser dude from the optical beam in the backward

15   direction has caused a change oscillation state of the laser diode.

In the case of the present invention, the laser diode is a surface-emission laser diode and operates in the long-wavelength band. Thus, the laser

20   diode has a generally circular beam shape characterized by excellent aspect ratio close to 1. Thereby, the efficiency of the laser diode is improved substantially as compared with the case of the edge-emission type laser diode.

25   Further, the laser diode of the present

invention has the reflector of very high reflectance
and the effect of the return beam is successfully
suppressed. Thereby, it becomes possible to couple
the laser diode and optical fiber directly, and the

5   optical isolator used in the conventional optical
telecommunication system can be eliminated.

        Designating the diameter of the laser
emission part 32A as d and the optical fiber core
diameter as F, it is possible to increase the optical

10   coupling efficiency by setting the parameters d and F
so as to satisfy the relationship

        $0.5 \leqq F/d \leqq 2$ (3)

        Hereinafter, the reason of this will be
explained with reference to Table 8, which summarizes

15   the result of the study of the inventor of the
present invention on the optical coupling loss.

<center>Table 8</center>

F/d	coupling loss (dB)	performance
0.4	>5	✕
0.5	3 - 5	◯
0.65	1	◯
2.0	3 - 5	◯
2.2	>5	✕

◯   good

×   poor

Referring to Table 8, it can be seen that
the efficiency of optical coupling is decreased when
the diameter d of the beam emission part 32A has

5   exceeded the core diameter F. On the other hand, it
can be seen also that as long as there is a
relationship d≦2F (in other words 0.5≦F/d), the
optical coupling loss can be suppressed within 3 - 5
dB. In the case the diameter d of the beam emission

10   part 32A is smaller than the core diameter, a highly
efficient optical coupling is achieved in the case
the emission angle of the laser diode, determined by
the diameter of the circle inscribing the beam
emission part 32A and the wavelength, is smaller than

15   the numerical aperture NA for allowing a single mode
optical coupling to a single mode optical fiber.

For example, in the case the core diameter
is set to 10μm and the core refractive index is
1.4469 and the clad refractive index if 1.4435, the

20   numerical aperture NA that enables single mode
optical coupling becomes 0.0995 at the wavelength of
1.3μm. The diameter d of the beam emission part 32A
corresponding to this is about 6.5μm.

On the other hand, even in the case the

25   diameter of the beam emission part 32A is less than

6.5μm, it is possible to suppress the optical
coupling loss to the level of 3 - 5dB when the
diameter of the beam emission part 32A is about 5μm.
From this, it is concluded that it is preferable to

5 choose the parameters F and d to satisfy the
relationship

$0.5 \leqq F/d \leqq 2$.

While the foregoing arguments have been for
the case of using a single mode optical fiber, the

10 foregoing condition is applicable also to the case of
using a multimode optical fiber coupling a single
mode optical fiber via a tapered optical waveguide.

Next, another example of the optical
telecommunication system of the present invention

15 will be described with reference to Figure 100.

Referring to Figure 100, the present
embodiment uses a coupling lens 353 between the
surface-emission laser diode 32 and the single-mode
optical fiber. The lens 353 may be formed of a single

20 lens or a lens system in which a plurality of lenses
are combined. In the case of constructing the lens
353 by a single lens, it is preferable to dispose the
lens 353 close to the beam emission part 32A of the
laser diode chip 32.

25 In the construction of Figure 100, it

becomes possible to suppress the optical coupling
loss effectively even in the case the diameter d of
the beam emission part 32A is set larger than the
core diameter of the optical fiber 353, by

5   appropriately choosing the lens power of the coupling
lens 353.

     In the case the core diameter is 10μm and
the diameter d of the emission part 32A is 20μm, for
example, the beam size is reduced by 1/2 by the lens

10   353. Thus, designating the focal distance of the lens
353 as f, the laser wavelength as λ, the radius of
the beam emission part 32A as ω_0 (=10μm) and the
refractive index as n, the focal distance f is
obtained by the relationship

15

$$\frac{\dfrac{\lambda \bullet f}{\pi\omega_0^2 n}}{\sqrt{1+[1+\dfrac{\lambda \bullet f}{\pi\omega_0^2 n}]^2}} = \frac{5}{10}$$

     In this case, the focal distance f becomes
about 140μm.

20   In the case of using a coupling lens, it is
possible to achieve an efficient optical coupling
when there holds a relationship between the
parameters d and f noted before as

$d \gtreqless f$, or

$F/d \lesseqgtr 1.$ (4)

Further reference should be made to Table 9 below.

5

Table 9

F/d	coupling loss (dB)	performance
1.2	>5	×
1.0	3 - 5	O
0.8	1	O

In the embodiment of Figure 100, the coupling lens 353 was provided by a single lens. On the other hand, it is possible to construct the lens 353 by a plurality of lenses. For example, as represented in Figure 101, the lens 353 may be formed of two lenses 353A and 353B.

Referring to Figure 101, the diverging beam from the beam emission part 32A is focused by the first lens 353A to the second lens 353B, and there is formed a beam waist at the plane of the second lens 353B. The lens 353B functions as the lens 353 of Figure 100. According to the present embodiment, it becomes possible to maintain a high coupling efficiency in the case a single lens cannot be

disposed near the beam emission part of the laser

diode or in the case the divergence of the beam is

excessive and the optical coupling efficiency is

decreased, by constructing the lens 353 by plural

5 lenses.

In the description heretofore, it was

assumed that a single mode optical fiber is used for

the optical fiber 352. On the other hand a similar

effect is achieved also in the case of using a

10 multimode optical fiber or a tapered optical ·

waveguide, as long as the relationship of Equation

(4) is satisfied.

In the construction that uses a

conventional edge-emission laser diode, there is a

15 possibility that the laser oscillation is influenced

by the return beam from the coupling lens, and it has

been necessary to provide an optical isolator. In the

case of the surface-emission laser diode, there is

provided a reflector structure of high reflectance

20 and the effect of the return beam is successfully

eliminated. Thus, it becomes possible to eliminate

the optical isolator.

Next, another embodiment constructed by a

surface-emission laser diode and the optical fiber

25 will be explained with reference to Figure 102.

Referring to Figure 102, the laser diode chip 32 includes a plurality of beam emission parts 32A arranged in the form of array. Of course, it is possible to dispose the laser diode chips 32

5   themselves in the form of array. Further, a plurality of laser diode chips may be arranged in the form of array.

In Figure 102, the optical fiber is coupled directly to the corresponding optical emission part

10   32A, and thus, it is possible to satisfy the Equation (3) explained before with reference to Figure 99. Thereby, it becomes possible to construct an optical telecommunication system of large capacity.

Figure 103 is an embodiment in which a

15   coupling lens is provided further to the construction of Figure 102. In the construction of Figure 102, too, the relationship between the beam emission part 32A, the lens array and the optical fiber 352 is the same as in the case of Figure 102. Thus, by satisfying the

20   Equation (4) by choosing the parameters d and F, an efficient optical coupling becomes possible. As the beam emission part 32A is arranged in the form of array, an optical telecommunication system of large capacity is realized. In the present embodiment, it

25   is possible to combine a plurality of lenses in each

of the coupling lens 355.

[Twenty-second Embodiment]

Next, another embodiment of the present
5 invention will be described.

Figures 104A and 104B show an example of
the optical telecommunication system that uses a
long-wavelength laser diode of the present invention
as an optical source and shows the state in which the
10 laser diode chip 32 carrying the beam emission part
32A is connected with a laser driver IC 32D including
a CMOS circuit, wherein Figure 104A shows a side view
while Figure 104B shows a plan view.

Referring to Figures 104Aa and 104N, the
15 laser diode chip 32 and the laser driver IC 32D are
mounted on a conductive submount 401 by a conductive
adhesive. Further, the laser diode chip and the laser
driver IC 32D are connected by a high-frequency
transmission line 402 (microstrip line in the present
20 embodiment), and each chip 32 is connected to this
microstrip line 402 by way of a bonding wire 403.

In the case of the surface-emission laser
diode for optical telecommunication, it is necessary
to carry out a very fast modulation in the order of
25 several hundred MHz to several GHz. Thus, it is

preferable to decrease the distance between the laser diode chip 32 and the laser driver IC 32D. On the other hand, there can be a case in which such a construction is not possible because of the layout of

5   the optical system. When an ordinary wiring is used in such a case for connecting the laser diode chip 32 and the laser driver IC 32D, however, there arise s problem of electromagnetic emission from such wiring. In the present embodiment, the laser diode chip 32

10   and the laser driver IC 32D are connected such that there occurs no such electromagnetic radiation.

By using such a construction, no electromagnetic emission occurs from the wiring part and the need of providing special shielding means is

15   eliminated. Thereby, the cost of the optical telecommunication system is reduced.

In the present embodiment, a microstrip line was used for the high-frequency transmission line 402. However, any of unbalanced transmission

20   line such as coplanar transmission line or triplate line may be used. Further, the connection between the laser diode chip 32 and the laser driver IC 32D is not limited to the bonding wired but flip-chip wiring or TAB bonding or microbump bondin may be used.

25

[Twenty-third Embodiment]

In the embodiment of Figure 52, a system that uses a surface-emission laser diode of long-wavelength band of 1.1 - 1.7 μm has been explained.

5 Conventionally, an optical telecommunication using the wavelength band of 0.85 μm band is studied. However, in this wavelength band, the optical transmission loss is large in the optical fiber and practical use of such a system was not successful.

10 Further, there has been no stable laser diode device in the long wavelength band in which the optical transmission loss is small. In the present invention, on the other hand, it became possible to construct a surface-emission laser diode operable in the

15 wavelength band of 1.1 - 1.7 μm by improving the semiconductor distributed Bragg reflectors 12 and 18 and by providing the non-optical recombination elimination layers 13 and 17, such that the laser diode operates stably at low power. Thereby, a

20 practical optical telecommunication system has become the matter of reality.

In the example of Figure 52, the optical telecommunication system is formed of the long-wavelength surface-emission laser diode chip, the

25 first optical fiber FG1 injected with the laser beam

emitted from the beam emission part 32A in the chip
32 and acting as an optical transmission path, a
second optical fiber FG2 injected with the laser beam
transmitted through the first optical fiber FG1 and
5   functioning as an optical transmission path, a third
optical fiber FG3 injected with the laser beam
transmitted through the optical fiber FG2 and
functioning as an optical waveguide, and a
photodetector chip 34 including a photodetection part
10 34A coupled optically to the optical fiber FG3 for
detecting the laser beam transmitted through he
optical fiber FG3.

        Further, the optical connection module MG1
is provided between the laser diode chip 32 and the
15 first optical fiber FG1, while the optical connection
module MG2 is provided between the optical fiber FG1
and FG2. Similarly, the optical connection module MG3
and FG4 are provided between the optical fibers FG2
and FG3 and between the optical fiber FG3 and the
20 photodetector 34.

        In the example of Figure 52, the first
optical fiber FG1 is coupled directly to the beam
emission part 32A of the laser diode chip 34 without
intervening an optical system.

25   With reference to Figure 94, a description

was made on the relationship that is required between
the laser diode of the present invention and the
optical fiber.

In the long-wavelength surface-emission
5   laser diode of the present invention, the optical
emission angle of the laser beam is about 10degrees,
and the laser diode is use din combination with an
optical fiber which may have a core diameter of 50μm
(clad diameter of 125μm).

10   In such a combination of the laser diode
and the optical fiber, the beam emission part 32A may
have a size of 0.005mm x 0.005mm - 0.002mm x 0.002mm.
In terms of area S, these are represented as
0.000025mm^2- 0.0001mm^2. In this case, it is possible
15   to achieve excellent optical coupling without the
need of providing an intervening optical system.
Further, the same result holds also in the case an
optical waveguide is used in place of an optical
fiber.

20   In the present invention, the beam emission
part 32 is tuned to the wavelength of 1.1 - 1.7μm,
while the foregoing wavelength band is related to the
operational voltage of the laser diode.

Thus, in the present embodiment, a detailed
25   analysis was conducted on the operational voltage of

the laser diode 32 suitable for realizing continues oscillation, not just a pulse oscillation.

Table 10 shows the experimental results of the present embodiments.

5

Table 10

No.	emission size (mm x mm)	area S (mm2)	voltage V	V/s	remarks
1	0.005x0.005	0.000025	0.2	8000	✕
2	0.005x0.005	0.000025	0.3	12000	✕
3	0.005x0.005	0.000025	0.375	15000	◯
4	0.005x0.005	0.000025	0.4	16000	◯
5	0.005x0.005	0.000025	0.5	20000	◯
6	0.005x0.005	0.000025	0.6	24000	◯
7	0.005x0.005	0.000025	0.75	30000	◯
8	0.005x0.005	0.000025	0.9	36000	✕
9	0.005x0.005	0.000025	1.2	48000	✕
10	0.01 x 0.01	0.0001	1.2	12000	✕
11	0.01 x 0.01	0.0001	1.3	13000	✕
12	0.01 x 0.01	0.0001	1.5	15000	◯
13	0.01 x 0.01	0.0001	1.7	17000	◯
14	0.01 x 0.01	0.0001	1.9	19000	◯
15	0.01 x 0.01	0.0001	2.1	21000	◯

16	0.01 x 0.01	0.0001	2.3	23000	O
17	0.01 x 0.01	0.0001	2.5	25000	O
18	0.01 x 0.01	0.0001	3	30000	O
19	0.01 x 0.01	0.0001	4	40000	X
20	0.01 x 0.01	0.0005	5	50000	X
21	0.02 x 0.02	0.0004	2	5000	X
22	0.02 x 0.02	0.0004	4	10000	X
23	0.02 x 0.02	0.0004	6	15000	O
24	0.02 x 0.02	0.00041	8	20000	O
25	0.02x 0.02	0.0004	10	25000	O
26	0.02x 0.02	0.0000	12	30000	O
27	0.02x 0.02	0.00004	15	37500	X
28	0.02x 0.02	0.00004	20	50000	X

O good oscillation

X no oscillation or damage

From the results above, it can be seen that, by choosing the operational voltage S such that the ratio of the operational voltage V to the area S of the beam emission part 32A of the laser diode (V/S) falls in the range of 15000 - 3000, it can be possible to drive the laser diode without causing a damage in the laser diode and the laser diode can be operated continuously. By choosing the drive conduction as such, it is possible to realize a

stable optical transmission system having along
lifetime.

[Twenty-fourth Embodiment]

Next, a further embodiment of the present
invention will be explained.

Figure 105 shows the construction of an
optical telecommunication system using the long-
wavelength laser diode according to the present
invention, wherein those parts corresponding to the
parts described previously are designated by the same
reference numerals and the description thereof will
be omitted.

Referring to Figure 105, the optical
telecommunication system of the present invention has
a construction to divide the optical output of the
laser diode 32A provided on a mount substrate 301
into an optical beam for optical telecommunication
and a monitoring beam by using the mirror 301
provided on the mount substrate 301A, wherein the
monitoring beam thus divided is detected by the
monitoring photodetector 142P provided on the mount
substrate 301A. The monitoring photodetector 142P
corresponds to the monitoring photodetector 142P
explained previously with reference to Figure 86. In
Figure 105, as well as in Figures 107 and 108 to be

described laser, there are formed a laser diode array
by the laser diodes arranged in the direction
perpendicular to the plane of the drawing. In
correspondence to this, there are provided a

5 plurality of optical waveguides.

The optical telecommunication system of the
present embodiment is formed of an optical
transmission part including the surface-emission
laser diode 32 and the driver circuit thereof, the

10 photodetection part including the planar
photodetection unit and a drive circuit thereof, and
an optical fiber or optical waveguide providing an
optical transmission path extending between the
optical transmission part and the optical reception

15 part. Although the driver circuit of the laser diode
32 or photodetector 34 is not shown, these can be
formed on the substrate of the respective devices.
Alternatively, these can be formed integrally with
the laser diode device in the device fabrication

20 process. By providing such an optical transmission
part and optical reception part at both ends of the
optical transmission path, it becomes possible to
realize a bi-directional optical telecommunication
system.

25   As represented in Figure 105, the laser

beam emitted from a surface of the long-wavelength
laser diode is divided by the mirror 301 and one of
the optical beams thus divided is then directed to
the optical waveguide 302 provided with an optical
5   alignment. This optical waveguide 302 may be an
optical fiber.

On the other hand, the other optical beam
divided by the mirror 301 is directed to the
monitoring photodetection device 34 provided on the
10   mount substrate 301A. Thus, the mirror 301 is used to
divide out the laser beam to be supplied to the
monitoring photodetector 34 and it is preferable that
such a mentoring optical beam is as weak as possible
within the range that a proper control of the laser
15   diode is possible by using such a monitoring device.
In view of the power consumption of the optical
telecommunication system, it is preferable to provide
as much energy as possible to the optical waveguide
302 as an optical signal.

20   Thus, in the present invention, the
thickness of the metal film of Au or Ag or Al used
for the mirror 301 such that the transmittance of the
mirror301 is controlled for the wavelength of 1.1 -
1.7μm. Further, it is also possible to provide
25   openings of various shaped in the form of grooves,

circles, squares, and the like, so as to control the transmittance of the mirror 301. Thereby, in order to avoid the effect of unwanted optical interference, it is preferable to change the pitch or size or location

5   of the openings at random. Further, it is possible control the transmittance of the mirror 301 by using a dielectric multilayer mirror or semiconductor layered mirror.

As compared with the conventional laser

10 diode of edge-emission type, the surface-emission laser diode used in the optical telecommunication system of the present invention has an advantageous feature of small output dependence on temperature and little degradation with time. While the laser diode

15 of the present invention has such advantageous features, it is nevertheless preferable to control the output thereof by way of feedback control.

In the case of a conventional edge-emission laser diode, such a monitoring of the optical power

20 of the laser diode was made easily by monitoring the laser beam emitted from the rear edge surface of the laser diode. In the case of the surface-emission laser diode, the laser output is obtained only at one side of the laser diode. Thus, the construction of

25 monitoring the laser beam emitted in the backward

direction cannot be used in the present invention.
Further, the laser diode ahs a relatively narrow
angle of optical emission of about 10degrees. Thus,
while there is a possibility of provide the laser

5   diode close to the optical fiber or optical waveguide,
there is no room at all for inserting a monitoring
photodetector between the laser diode and the optical
fiber.

On the other hand, the present invention

10   provides an effective an simple means of obtaining a
monitoring laser diode by providing the mirror 301 as
noted above. Thereby, the output of the laser diode
is monitored with out increasing the optical path,
and the output of the laser diode is controlled

15   positively and exactly. As the present invention uses
the mirror 301 for deflecting the output optical beam
of the laser diode, the optical axis of the reflected
signal optical beam becomes parallel to the optical
axis of the optical fiber, and thus, it becomes

20   possible to fix the optical fiber or optical
waveguide on a plane parallel to the plane of the
optical module and the optical waveguide 302 or
optical fiber is fixed easily. Thereby, the obtained
structure has an improved rigidity. Further, it is

25   also possible to provide a lens before or after the

mirror 301.

Although not illustrated, it is possible to use a plurality of laser diodes and corresponding optical waveguides or optical fibers. In this case,

5   the laser diodes are arranged in a direction perpendicular to the sheet of the drawing, and the mirror 301 extending also in the direction perpendicular to the sheet of the drawing is used commonly by the laser diodes forming the array.

10   Figure 106 shows the block diagram of the feedback circuit that controls the output of the laser diode 32 by using the divided laser beam.

Referring to Figure 106, the laser diode 32 is driven by a driver circuit 161 corresponding the

15   driver circuit 161 explained previously with reference to Figure 87, and a part of the laser beam produced by the laser diode 32 is provided to the monitoring photodetector 142P. The monitoring photodetector 142P detects the output of the laser

20   beam thus supplied and produces an electric output current indicative of the output of the laser diode 32. Further, the laser control part 162 controls the laser diode 32 such that the output of the laser diode is maintained constant.

25   In the construction of Figure 106, it

should be noted that the laser diode 32 can be driven with a low drive voltage. Thereby, ordinary CMOS circuit can be used for the driver circuit 161. Thereby, power consumption of the laser diode is

5 reduced. As the wavelength band to be detected by the monitoring photodetector 142P is in the range of 1.1 – 1.7μm, it is possible to use a photodiode of the InGaAs system. Further, in view of the gradual change of the output of the laser diode, it is not necessary

10 that the photodetector 142P has a high response speed. Thus, it is possible to use a high-sensitivity photodetector while sacrificing the response speed.

Referring back to Figure 106, there is formed a laser diode array including four laser

15 diodes 32A each having the construction of Figure 1, and the laser diode array is mounted on the mount substrate 301 of Si together with the drive circuit and the laser control circuit not illustrated. The laser diodes 32A has the wavelength of 1.3μm and may

20 be disposed on a single chip 32 with the pitch of 200 μm.

Next, the mirror 301 is formed by using a heat conductive Si substrate, which is transparent to the wavelength of 1.3μm. By using the Si substrate

25 for the mount substrate 301A, it is possible to form

the mirror easily by conducting an anisotropic
etching process. Thereby, a crystal surface
determined with respect to the principal surface of
the substrate 301A is formed with exact angle. The
5   etching process may be conducted by using an etchant
such as KOH. With this, a mirror surface having a
45degrees is formed. Further, an Au deposition is
conducted on the mirror surface 301, and the optical
waveguide 302 is formed. In such a process, it is
10   possible to control the transmittance of the mirror
301 by controlling the thickens of the Au film.

In the formation of the optical waveguide
302, it should be noted that a PMMA film is formed as
the core layer after the cladding layer 302A is
15   formed. By patterning the core layer thus formed, the
core pattern 302B is formed. Further, the upper
cladding layer 302C is formed so as to cover the core
layer 302B.

In the present embodiment, the core pattern
20   302B is patterned so as to form a cross section of 50
x 50 μm. The optical waveguide layer 302 thus formed
is coupled with the optical fiber not illustrated,
and long distance optical telecommunication system
is constructed.

25   For the optical waveguide layer 302, it is

possible to use various resins such as polyimide, epoxy resin, polyurethane or polyethylene, in addition to PMMA. Further, it is possible to provide an inorganic film such as silicon oxide film. Further,

5 the formation of the optical waveguide layer 302 can be made by combining the spin coating process or dip coating process and a patterning process. Alternatively, it is possible to form the optical waveguide by a resin molding ;process or molding

10 process.

Further, the optical axis of the laser diode is set coincident with the optical axis of the optical waveguide, and the mount substrates 301 and 301A are fixed. Further, a planar photodiode is

15 mounted on the mount substrate 301A in optical alignment with the laser beam divided by the mirror 301 as the monitoring photodetector 142P. A photodiode having an optical absorption layer of InGaAs on the InP substrate may be used of this

20 purpose.

Further, the output of the photodetection device 142P is connected to the laser control unit 162 by a wire bonding process. With this, the feedback control circuit explained with reference to

25 Figure 106 is obtained.

Table 11 below shows the result of
evaluation of the optical transmission unit conducted
by changing the external temperature.

Table 11

mirror transmissivitgy (%)	remarks
0.1	×
0.2	×
0.3	×
0.5	△
0.7	△
1.0	◯
2.0	◯
5.0	◯
10	◯
20	◯
30	◯
40	◯
50	◯
60	△
70	×

◯   good

△   fair

×   poor

In the experiment, the temperature is

changed from 0 - 70°C with the step of 10°C, wherein Table 11 shows only the result of 20°C, as the results for other temperatures were more or less the same as the result of 20°C.

5   Referring to Table 11, it can be sent that an optical power of 10μW is detected by the monitoring photodetector 142P when the mirror transmissivity is less than 1% for the optical power of mW level, which is used commonly for optical

10 telecommunication. As the change of the optical power of the laser diode is smaller than this, no sufficient optical energy needed for the control of the laser diode is supplied to the photodetection device, and as a result, there is a fluctuation of

15 optical output in the laser diode.

When the transmissivity exceeds 50%, on the other hand, too much energy of the laser output is used for controlling the output power of the laser diode. Thus, there occurs decrease of efficiency of

20 the optical telecommunication system.

From the result of Table 11, it can se seen that the transmissivity of 2% or more but 30% or less is preferable for the mirror 301. By using such a construction, it is possible to realize an optical

25 transmission unit capable of controlling the laser

output stably. Thereby, it is preferable that the
transmissivity of the mirror 301 is in the range of
1% or more but 50% or less, more preferably 2% or
more but 30% or less.

5   In the present embodiment, 4 laser diodes
were used in the form of array. Of course, the number
of the laser diode may be one, or the laser diode may
be used in the form of array including 8, 12, 16 or
more laser elements.

10   It is also possible to use an optical fiber
for transmitting the optical signals in place of the
optical waveguide 301. When transmitting large amount
of information over a long distance, the use of
single mode optical fiber is suited. In the case of

15 transmitting information for short distance with low
cost, the use of plastic optical fiber (POF) is
suitable. Further, there may be a possibility of
using a multimode optical fiber in the intermediate
applications.

20   Figure 90 shows another embodiment of the
present invention in which the electrode of the
photodetection device is used for the mirror.

           In the present embodiment, the long-
wavelength laser diode 32 of Figure 1 is mounted on

25 the Si mount substrate together with a driver circuit

and a laser control circuit not illustrated. In the
present embodiment, a laser diode having a laser
oscillation wavelength of 1.2 μm is used.

Similarly to the previous embodiments, a
5   photodetector using a GaAsP material is used for the
monitoring photodetector 142. In the present
embodiment, the p-type electrode of the optical
detection surface is used for the mirror 301.

More specifically, an Au film having a
10   thickness of 300 nm and not allowing passage of the
1.2 μm wavelength radiation is provided on the
photodiode as the electrode, and circular openings
having various diameters in the range of 0.7 - 5 μm
are formed. With this, a transmissivity of 5% is
15   realized.

The photodiode 142P thus formed is mounted
with an angle of 45degree with regard to the laser
diode 32, and the output of the photodiode 142P is
connected to the laser control unit 162 electrically.
20   Thereby, there is formed a feedback control system of
the laser diode similar to the one shown in Figure
106.

By providing a multimode optical fiber 302F
having a core 302f of 50 μm diameter and a clad of
25   125 μm diameter in optical alignment with the laser

beam reelected by the mirror 301, an optical
telecommunication system is constructed. Such an
optical telecommunication system is simple in
construction with reduced number of parts, and it is
5   possible to provide a compact optical transmission
module. Such an optical transmission module can
control the laser output stably and a reliable
optical telecommunication is realized. In the present
embodiment, it is also possible to form the mirror
10   301 on the surface of the monitoring photodetection
device separately to the electrode.

Next, another embodiment of the present
invention will be explained with reference to Figure
108.

15   Referring to Figure 108, the present
embodiment provides the long-wavelength surface-
emission laser diode 32 mounted on the Si mount
substrate 301 together with the driver circuit and
laser control circuit not illustrated. In the
20   illustrated example, four laser diodes 32A are
arranged with the pitch of 200μm, wherein each of
the laser diodes has a laser oscillation wavelength
of 1.3μm.

In the present embodiment, the edge of the
25   optical waveguide is cut to form a 45degree angle by

a diamond blade, and the mirror 301 is formed by
covering the oblique surface thus formed by an Au
film. Thereby, the thickness of the Au film is
controlled such that the Au film has a transmissivity
5   of 3%. The optical waveguide 302 thus processed is
coupled optically with the laser diode 32 by
achieving optical alignment, and the monitoring
photodetector 142P is mounted on the optical path of
the optical beam divided by the mirror 301. According
10   to such a construction, it is necessary to control
the output of the laser diode 32 via the control unit
162 in response to the output of the photodetector
142. By doing so, it becomes possible to construct an
optical module of simple construction and reduced
15   number of parts.

[Twenty-fifth Embodiment]
        Next, another embodiment of the present
invention will be described.
20   Conventionally, edge-emission laser diodes
are used extensively in optical telecommunication
systems. When using such an edge emission laser diode
in combination with plural optical fibers, there is a
need of achieving optical coupling for each of the
25   laser diodes one by one. In the case of an edge-

emission laser diode, there is another problem of
large beam divergence in that the laser beam spreads
rapidly due to the large emission angle. Further, the
emission angle is different in the lateral direction

5   and vertical direction, and the laser beam shows an
elongated beam spot characterized by poor aspect
ratio. Thus, in the case of conventional edge-
emission laser diode, it has been necessary to
provide a coupling lens for each of the laser diodes.

10   Because of these reasons, it was not
possible to form the laser diode in the form of high
density array in the case of using conventional edge-
emission type laser diode.

        In contrast, the present invention has

15   enabled the construction of a high-density laser
array by using a number of surface-emission laser
diodes commonly on a single chip monolithically. By
combining optical fibers with the laser diode array
thus formed, a large capacity optical transmission

20   system is realized.

        Figures 110A and 110B show an example of an
optical telecommunication system in which the long-
wavelength laser diodes of 1.1 − 1.7 μm are used in
combination with optical fibers.

25   As represented in Figure110A, the surface−

emission laser diode of the present invention is characterized by a narrow divergence of the optical beam in any of the horizontal and lateral directions of the beam spot. In fact, the laser beam produced by

5   such a surface-emission laser diode is characterized by a circular beam cross-section.

In contrast, the laser diode of the edge emission type laser diode produces an optical beam diverging rapidly with large emission angle, wherein

10   the laser beam produced by such an edge-emission layer diode shows a beam shape characterized by an eclipse. Thus, the size of the laser beam spot is different in the horizontal direction vertical direction.

15   Thus, by using the surface-emission laser diode of the present invention, it becomes possible to construct a large capacity optical transmission system by arranging a number of optical fibers with high density.

20   In the case of such a high-density telecommunication system, it is difficult to use coloring layer or identification ring used commonly in ordinary optical fiber capes for identifying reach of the optical fibers In the cable.

25   In the case of the surface-emission laser

diode, it is possible to form each beam emission part 32A constituting the array simultaneously and in high density by using the lithographic process. In the case of handling a number of optical fibers in such a

5   laser diode array, it is more preferable to handle the optical fibers in the form of bundle, rather than handing each of the optical fibers. Particularly, it is preferable to make a correlation between the optical fibers bundled in the form of a cable and the

10 laser diodes in the array.

On the other hand, in the case the optical fibers 101 are assembled to form a bundle, it is not easy to identify the center of the bundle or individual optical fibers in the bundle.

15 For example, in the case the cladding 101b of the optical fiber 101X at the center of the optical fiber bundle is colored as represented in Figures 111A - 111C, the recognition of the optical fiber is easy.

20 Thus, it is possible to achieve the correlation between the laser diodes in the array and the optical fibers in the bundle by first turning on the laser diode 32AZ at the center of the array. Thereby this laser diode is correlated with the

25 colored optical fiber at the center of the bundle.

In the example of Figures 112, it can be
seen that four fibers are colored at cladding layer.
By correlating these four optical fibers with four
laser diodes, it is possible to easily establish the
5   correspondence between the optical fiber and the
laser diode for other optical fibers.

It should be noted that the cladding layer
of an optical fiber is used merely for confining the
light in the core. Thus, coloring of the cladding
10   layer 101b as shown in Figures 113A and 113B does not
cause a problem at all with regard to the information
transmission, which takes place through the core 101a.

Figures 111B and 111C show a modification
of Figure 111A. In the example of Figure 111A, the
15   optical fibers 101 are arranged in a closest packing
state. In the case of Figure 111B, on the other hand,
optical fibers are arranged in a square grid. Further,
Figure 111C shows an example of uses a ferule 101F
for marinating the square grid arrangement of the
20   optical fibers.

Figure 114 shows an example of a single
mode optical fiber. As compared with the optical
fibers of multimode represented in Figures 113A and
113C, the core diameter of the single mode optical
25   fiber is very small with regard to the diameter of

the cladding layer of 125μm, and the area of the
cladding layer 101b with respect to the core 101a can
reach 172 times as large as the core area of the
multimode optical fiber. In the case of the single
5   mode fiber, recognition of the optical fiber by using
the color layer is facilitated further.

[Twenty-sixth Embodiment]

Next, another embodiment of the present
invention will be explained. In the conventional
10   laser diode, there has been a problem that the
threshold current is changed depending on the
temperature. In a telecommunication system, the use
of the laser diode at strictly constant temperature
is difficult. Thus, in the case of the edge-emission
15   laser diode, it has been practiced to detect the
leakage light emitted in the backward direction by a
photodetector and the output off the photodetector
has been used for a feed back control of the laser
outputs such that the output of the laser diode is
20   maintained constant.

In the case of the surface-emission laser
diode, however, such detection of the leakage light
is not possible. Thus, in the conventional surface-
emission laser diode, it has been practiced to
25   provide a photodetector between the laser diode and

the optical fiber or at the downstream side of the
optical fiber, and the feed back control has been
applied by using such a photodetector such that the
output of the laser diode is maintained constant.

5   Figure 115 shows an example of the I-L
(current-optical output) characteristic of the long-
wavelength laser diode of the present invention.

    Referring to Figure 115, the laser diode of
the present invention has a feature, contrary to the
10 conventional laser diode, in that the change of the
threshold current with temperature is very small.
Only the slope of the curve is influenced with the
temperature.

    Thus, as long as the laser diode is driven
15 at a constant drive voltage, the change of the
optical output is small even in the case there is a
temperature change.

    For example, in the case the laser diode is
driven at the drive current of 6mA in Figure 115, the
20 change of optical output associated with the
temperature change from 10°C to 70°C is only 0.1mW.
Even when the temperature is changed from 10°C to
100°C, the change of the optical output is only
0.25mW. In terms of S/N ratio, this is respectively
25 26dB and 18dB. Thus, the laser diode of the present

invention can provide a sufficient signal quality in the commonly used temperature environment of 20 - 70°C.

It should be noted that the drift of

5 current of a constant current source is in the order of ±2 - 3%. Thus, it is easy to achieve a constant current control.

Thus, by setting the upper limit and lower limit for the optical output and further setting the

10 upper limit and lower limit for the temperature, the present embodiment achieves the desires control of the optical output within the foregoing upper and lower limits by controlling the drive current at a constant value x between a first reference drive

15 current a corresponding to the upper limit optical output at the lower limit temperature and a second reference drive current b corresponding to the lower limit optical output at the upper limit temperature.

According to the present invention, the

20 laser diode is driven at a constant current determined with respect to the target optical output.

[Twenty-seventh Embodiment]

The threshold current of the laser diode

25 increases gradually with time and when the threshold

current has exceeded a predetermined value, it is the lifetime of the laser diode.

Thus, there is a demand to avoid deterioration of signal quality even when the aging
5   is in progress.

As shown in Figure 117, for example, there is provided a half mirror 411 in the transmission path 410 coupled to the laser diode 32, and the optical beam thus divided is detected by the
10   photodetection device 412. In this case, the intensity of the laser beam detected by the photodetection device, in other words the monitor optical strength, is fed back to the control unit 415 and the constant current source 416.

15   In the illustrated example, the output of the photodetection device 412 is supplied to the communication control unit 414, and the communication control unit 414 obtains the correction of the drive current by referring to a conversion table 414A
20   representing the relationship between the monitor optical output and the correction of the drive current. According to such a construction, it is possible to eliminate the effect of aging by removing the change of optical output caused by aging. Thereby,
25   a practical telecommunication system is realized.

In order to monitor for the aging or
anomaly related to the aging, it is sufficient that
the output of the photodetection device at the
reception end can be obtained. Thus, it is also
5   possible to transmit the reading of the
photodetection device at the reception side in the
form of data to the transmission side. For example,
it is possible to transmit the reading of the
photodetection device periodically or at any time to
10 the optical transmission side, separately to the
optical telecommunication data. The data thus
transmitted may be forwarded in the transmission side
from the communication control unit to the laser
control unit for correcting the drive current. By
15 doing so, it is possible to eliminate the fluctuation
of optical output caused by aging.

[Twenty-eighth Embodiment]

Next, a further embodiment of the present
20 invention will be described.

Figure 118 shows an example of an optical
telecommunication system that uses a long-wavelength
laser diode 32 of the present invention.

Referring to Figure 118, it can be seen
25 that the system includes a laser diode module

connected with an optical fiber 421, an optical
circuit substrate 423 carrying the laser diode module
422, and electronic substrates 423B and 423C provided
above and below the optical circuit substrate 423A.

5   The circuit substrates 423A - 423C are accommodated
in a case 420, wherein the substrates 423A - 423C
form a air flow path in the case 420. Further, the
case 420 is provided with a fan 424A, and an air
outlet is formed on the case 420 at the side opposite

10   to the fan 424A. The electronic substrates 423B and
423C carry electronic components 423a thereon.

The fan 424A may be a compulsory air-
feeding fan such as sirocco fan, and supplies a
cooling air inside the case 420. The cooling air

15   flows along the space between the substrates 423B and
423C and there takes place heat exchange between the
air and the laser diode module 422 as the cooling air
is caused flow along the substrates. The cooling air
thus exchanged heat is expelled from the air outlet.

20   424B

In the illustrated example, the substrate
423B of the smallest heat generation is provided at
the lower part and the substrate 423C causing a
larger heating is provided thereabove.

25   It should be noted that the surface of the

optical substrate 423A facing the electronic
substrate 423C is reduced with projections or
depressions so as to minimize disturbance of air flow.
Meanwhile, a similar effect is obtained also in the
5   case in which a flat board carrying no electronic
components is used for trhe electronic substrates
423B or 423C. While the present embodiment uses only
one fan 424A, it is possible to increase the number
of fans with the number of the laser diodes provided
10   in the case 420. It should be noted that the heating
is increased when the number of the laser diodes is
increased. Alternatively, it is possible to increase
the flow rate of the air. In this case, the area of
the air outlet has to be increased.

15   It is also possible to use the fan 424A to
pull the air inside the case 420. Further, it is
possible to provide a fan in the air intake side and
another fan in the air outlet side.

20   [Twenty-ninth Embodiment]
          Figure 119 shows an example of the laser
diode module that uses the long-wavelength laser
diode 32 of the present invention.
          Referring to Figure 119, it can be seen
25   that two laser diodes 32A are formed on the GaAs

substrate 32 monolithically, and the GaAs substrate 32 is carried by a Si mount substrate 131 having a large thermal conductivity. Further, the Si substrate 131 is carried on a ceramic substrate 1363 having a

5 still larger thermal conductivity. The ceramic substrate 136 is mounted on an optical circuit board such as the substrate 434A shown in Figure 101. The ceramic substrate 136 is cooled.

Further, electric interconnection to the

10 laser diode 32A is provided by way of bonding wires connecting an electrode 136A on the ceramic substrate 136 and the electrode on the laser diode 32A.

With such a construction, the heat generated by the laser diode 32A is transferred to

15 the GaAs substrate by thermal conduction and then to the Si substrate 131 of lower temperature. Further, the heat is transferred to the ceramic substrate 136 of lower temperature, and efficient cooling of the laser diode 32A becomes possible. It should be noted

20 that the surface area of the ceramic substrate 136 is the largest among the constituent parts, and thus, the ceramic substrate 136 is cooled efficiently by radiation and contact with the air.

The GaAs substrate constituting the laser

25 diode chip of the present invention has a thermal

conductivity of 0.54W/cmK, while it is noted that the thermal conductivity of Si is 1.48W/cmK. Further, a material having a larger thermal conductivity than Si such as BeO (2.72W/cmK) or diamond (9.0W/cmK) can

5 also be used, wherein the value of the thermal conductivity is the value at 300K.

Meanwhile, thermal transfer across tow substrates contacting with each other can be increased by reducing the surface roughness and

10 increasing the intimateness. On the other hand, excessive processing of the surface merely invites increase of cost and the improvement of heat transfer is little. For example, the precision of surface flatness beyond 10 nm merely increases the cost and

15 is not practical. Thus, the lower limit of the surface roughness should be around 10nm.

With regard to the upper limit of surface roughness, excessively rough surface is disadvantageous for contacting two substrates. Thus,

20 the inventor of the present invention conducted extensive study about this matter and discovered that the surface roughness of 1000nm or less is sufficient for guaranteeing intimate contact and excellent heat transfer. In the experiments conducted by causing the

25 laser diode to oscillate, it was confirmed that the

heat generated by the laser diode 32A is transferred
from the laser diode chip 32 to the first substrate
131, and to the second substrate 136, without causing
accumulation of heat. With this, it became possible
5   to reduce the fluctuation of threshold current of the
laser diode caused by heating. Thereby, it became
possible to cause the laser diode to oscillate stably.

Figure 120 show an example of the long-
wavelength laser diode module of the present
10   embodiment, wherein the GaAs substrate 32 carrying
the laser diode 32A is fixed upon the Si mount
substrate 131 via a thermal conduction layer 137, and
the Si mount substrate 131 is mounted on the ceramic
substrate 136 via another thermal conduction layer
15   138.

In the present embodiment, the contact
surfaces of the substrates 32, 131 and 136 are
polished by using an alumina abrasive to a surface
roughness Ra of 10 - 1000nm, and any gap formed
20   therebetween is filled with the thermal conductive
layer 137 or 138.

Here, it should be noted that the thermal
conductive layer 137 or 138 may be formed of an
organic polymer material such as epoxy resin or
25   silicone resin or acryl resin dispersed with metal

powders such as aluminum or gold or silver or copper.
The metal powders have a diameter of several
nanometers to 100 nm and the resin layer is applied
with a thickness of 3 - 100 μm. The proportion of
5 the metal powders was set to 0.1 - 1 part with regard
to 1 part of resin.

Figure 121 is an example of a long-
wavelength laser diode of the present embodiment and
is formed of a laser module package 431 including the
10 laser diode module 422 of Figure 118 and an optical
fiber 421.

At the bottom part of the package 431,
there is provided a cooling fin structure 431A having
eight cooling fins each having a rectangular cross-
15 section, with a base length of 1 mm and a height of
3mm, and the cooling air is caused to flow along the
cooling fin structure 431A.

It should be noted that the outer surface
of the laser module package 431 performs also as a
20 heat-radiating member similar to the ceramic
substrate 136, in addition to the function of the
packaging of the laser diode. It should be noted that
the surface on which the cooling fins are provided
ins not limited to the bottom surface but may be
25 other surface along with the cooling air is caused to

flow. Further, the number and construction of the
cooling fins are by no means limited to the one
illustrated.

The point of the present embodiment is to
5   provide, in a heat radiating structure in which a
first substrate including a heat source and a second
substrate not including a heat source are stacked,
such that the surface area of the part of the second
substrate not contacting with the first substrate is
10 set larger than the surface area of the second
substrate contacting with the first substrate. Any of
the structure may be used in place of the cooing fin
as long the structure increases the surface area of
the second substrate.

15   As noted previously, in the surface-
emission laser diode oscillating at the wavelength of
$1.1 - 1.7 \mu m$, it is possible to form a number of
laser diodes on a common chip and is suitable for
large capacity optical telecommunication system.
20 However, design of such a construction including a
large number of laser diode has to be made carefully
in view of severe heating. The present embodiment
provides a solution to this problem. Larger the
number of the laser diodes, more effective the
25 construction of the present embodiment.

[Thirtieth Embodiment]

Figures 122 and 123 show another embodiment of the present invention, wherein Figures 122 shows
5 the case a number of long-wavelength surface-emission laser diodes 32A of the present invention are used to form a one-dimensional array, while Figure 133 show the case the laser diodes form a two-dimensional array.

10 In the drawings, the laser diode elements 32A provided with shading have corresponding photodetection devices, while other elements have no photodetection device and the output thereof is taken to the outside.

15 Figure 124 shows the construction of Figure 122 from a different angle. It can be seen that the laser diode elements 32A provided with the shading is provided with the photodetection device 142P and the photodetection device 142P interrupts the laser beam.
20 On the other hand, the laser beam of the laser diode 32A not provided with the photodetection device 142P is injected into the optical fiber 352 by the lens 353.

The optical output of the laser diode 32A
25 not provided with the photodetector 142P is

calculated based on the output of the photodetector(s) 142P located in the vicinity thereof. Based on the output of the photodetector 142P thus obtained, output of each of the laser diodes 32A is

5 controlled. The variation of output between the laser diodes 32A is easily corrected by using a correction coefficient obtained in advance.

Figures 125 - 127 show an example of output control of the laser diode using the construction of

10 Figure 124.

Referring to Figure 125, the laser diode chip 32 includes a one-dimensional array of laser diodes 32A similar to Figure 122. For the sake of convenience of explanation, the laser diodes 32A in

15 Figure 125 are provided with numbers (0) - (6).

<Example 1>

In Example 1, the out put of the photodetection device 142P that monitors the output

20 of the first laser diode 32A (1) is used for controlling the drive currents of the laser diodes 32A (0) - (6) of Figure 125 by using the driver circuit 106 of Figure 106 such that

I_0 is controlled based on the value of $a_0 O_0$;

25 I_1 is controlled based on the value of $a_1 O_0$;

I_2 is controlled based on the value of a_2O_0;

I_3 is controlled based on the value of a_3O_0;

I_4 is controlled based on the value of a_4O_0;

I_5 is controlled based on the value of a_5O_0; and

5   I_6 is controlled based on the value of a_6O_0,

wherein I_i represents the drive current of the i-th

(i = 0 - 6) laser diode 32A and O_1 represents the

optical output of the i-th laser diode 32A. Further,

a_i represents a correction coefficient and is

10   determined in advance by measuring the output of

respective laser diodes such that the output

calculated based on the drive current is closest to

the actual laser output.

15   <Example2>

In Example 2, the out put of the

photodetection device 142P that monitors the output

of the first laser diode 32A (1) is used for

controlling the drive currents of the laser diodes

20   32A (0) - (6) of Figure 125 by using the driver

circuit 106 of Figure 106 such that

I_0 is controlled based on the value of a_0O_0;

I_1 is controlled based on the value of $a_1O_0+b_1O_3$;

I_2 is controlled based on the value of $a_2O_0+b_2O_3$;

25   I_3 is controlled based on the value of a_3O_3;

I_4 is controlled based on the value of $a_4O_0+b_4O_6$;

I_5 is controlled based on the value of $a_5O_0+b_5O_6$; and

I_6 is controlled based on the value of a_6O_6.

5   \<Example 3\>

In Example 3, the out put of the photodetection device 142P that monitors the output of the first laser diode 32A (1) is used for controlling the drive currents of the laser diodes

10   32A (00) – (44) of Figure 128 by using the driver circuit 106 of Figure 106 such that

I_{00} is controlled based on the value of $a_{00}O_{00}$;

I_{01} is controlled based on the value of $a_{01}O_{00}$;

I_{10} is controlled based on the value of $a_{10}O_{00}$;

15   I_{11} is controlled based on the value of $a_{11}O_{00}$;

I_{02} is controlled based on the value of $a_{02}O_{03}$;

I_{03} is controlled based on the value of $a_{03}O_{03}$;

I_{04} is controlled based on the value of $a_{04}O_{03}$,

...

20   I_{12} is controlled based on the value of $a_{12}O_{03}$;

I_{13} is controlled based on the value of $a_{13}O_{03}$;

I_{14} is controlled based on the value of $a_{14}O_{03}$,

... ,

wherein a_{ij} is a correction coefficient.

25   \<Example 4\>

In the example of Figure 129, the ij-th laser diode 32A of Figure 129 is controlled such that

I_{00} is controlled based on the value of $a_{00}O_{00}$;

I_{01} is controlled based on the value of

5    $a_{01}O_{00}+b_{01}O_{04}+ c_{01}O_{22}$;

I_{11} is controlled based on the value of $a_{11}O_{00}+b_{11}O_{22}$;

I_{21} is controlled based on the value of $a_{21}O_{00}+b_{21}O_{22}+c_{21}O_{10}$;

10   ...

In Example, 4, a_{ij}, b_{ij} and c_{ij} are correction coefficients.

[Thirty-first Embodiment]

15   Next a further embodiment of the present invention will be explained.

The present embodiment is related to the production control of the laser array module that uses the laser diode of the present invention and

20   used for the long-wavelength optical telecommunication.

Here, it should be noted that the laser array module means that a plurality of surface-emission laser diodes are provided in the form of a

25   module and includes the case in which a number of

laser diodes are formed on a single chip or the case in which a number of such chips are arranged. Further, the case of plural chips, each carrying a single laser diode, are arranged is also included.

5   In the production process of such a laser diode module, laser chip modules carrying a laser diode array are produced.

In such a production process, a predetermined number of laser diode devices or laser

10   diode chips are prepared and these elements are arranged to form the desired laser array module.

Thereafter, an inspection process is conducted with regard to the laser diode modules, wherein the inspection is conducted for each of the

15   laser diode chips and each of the laser diodes. Upon confirmation that a desired quality is achieved for each of the devices and each of the chips, the laser array module becomes the state ready for shipping.

In the case there is detected a single

20   device out of n devices of laser diode chips arranged to form the laser array module is defective, the laser chip module is treated as a defective product.

On the other hand, if it is possible to treat a laser chip module, in which the number c of

25   the defective laser diodes or chips is within a

predetermined number n of good products, as being a good product, the productivity of the laser array module is increased significantly.

The inventor of the present invention realized the importance of such a product control process and diligently studied the production control process applicable to the case of producing a product that uses a large number of elements each performing a single and same function as other elements.

Hereinafter, the present embodiment will be described with reference to Figures 130 and 131.

Referring to Figure 130, the production of the laser diode or chip is conducted according to the step S1 of wafer process step, step S2 for producing a laser diode array step, and S3 for producing a laser array module. Further, there is provided an inspection step S4 for inspecting the array or module produced by the steps S2 and S3.

In the present embodiment, the laser array module that turned out to include a defective device or defective chip is not immediately treated as a defective product. In the event the number c of the defects is within a certain threshold (n-c) (n is the total number of the devices or chips in the module), the product is shipped as the product having the

quality of (n-c). In the process of Figure 113, this examination step is conducted at the step S6. In the case the entire chips n are defective, the laser diode module is treated as a defective device.

5   Thus, in the step S4, of Figure 131, an inspection step S41 is conducted for evaluating the product quality for each channel CH by using a high-frequency probe or analyzer.

The data of the product quality for each
10 channel thus obtained is then examined in the product examination step S42, wherein the step S42 judges whether or not the required quality is satisfied for all of the laser diodes or chips. The judgment is made with regard to the items such as I-L
15 characteristic, I-V characteristic, fiber coupling loss, pulse modulation characteristic, temperature dependence, and the like. Thereby, the laser array modules are shipped according to the grades corresponding to the number of the properly
20 functioning laser diode chips.

From the explanation noted above, it will be apparent that the present embodiment enables the use of most of the laser array modules, used for the optical telecommunication system by using the
25 surface-emission laser diode of $1.1 - 1.7\,\mu$m,

according to the condition of the module.

According to the present embodiment, therefore, the laser array modules are used effectively even in the case only n-c of the laser

5   diodes operate properly, and the loss of the laser array module during the production process is minimized.

[Thirty-second Embodiment]

10   In the thirty-second embodiment of the present invention, there is provided a semiconductor distributed Bragg reflector comprising an intermediate layer between two semiconductor layers of different kind, said two semiconductor layers of

15   different kind having respective, different refractive indices, said intermediate layer having a refractive index intermediate between said refractive indices of said two semiconductor layers of different kinds, wherein said intermediate layer has a

20   thickness such that said thickness is different in a part of a region inside said semiconductor distributed Bragg reflector and in other regions.

Figure 132 shows an example of the semiconductor distributed Bragg reflector of the

25   thirty second embodiment of the present invention. It

should be noted that the semiconductor distributed Bragg reflector of Figure 132 is a p-type semiconductor distributed Bragg reflector having a designed reflection wavelength of 0.98μm and is

5   formed on a GaAs substrate by using an MOCVD process.

The p-type semiconductor distributed Bragg reflector of Figure 132 is produced by using trimethyl aluminum (TMA) and trimethyl gallium (TMG) for the group III source material and an arsine

10   (AsH_3) gas is used for the group V material. Further, CBr_4 is used for the dopant of p-type.

It should be noted that the semiconductor distributed Bragg reflector of Figure 132 is formed of consecutive stacking of a p-type semiconductor

15   distributed Bragg reflector I and a p-type semiconductor distributed Bragg reflector II, and there is provided a linearly graded layer between the different semiconductor layers having respective, different refractive indices and constituting the

20   semiconductor Bragg reflector, as an intermediate layer (semiconductor layer) having a refractive index intermediate of the foregoing refractive indices. In the linearly graded layer, it should be noted that the Al content is changed linearly from a first

25   composition to a second composition as represented in

Figure 133. Here, Figure 133 is a diagram showing the band energy for the part in the vicinity of the graded layer. It should be noted that the compositional graded layer can be grown easily by

5   using an MOVCD process, as the AlGaAs content can be changed easily by controlling the supply quantity of the source materials.

Here, it should be noted that the thickness of the intermediate layer (linearly graded layer) is

10   changed between the one provided in the p-type semiconductor distributed Bragg reflector I and the one provided in the p-type semiconductor distributed Bragg reflector II, wherein the semiconductor distributed Bragg reflectors I and II are stacked

15   consecutively in a stacking direction in the semiconductor distributed Bragg reflector of the thirty-second embodiment.

Figure 134 shows the construction of the p-type semiconductor distributed Bragg reflector I of

20   Figure 132, while in Figure 135 shows the construction of the p-type semiconductor distributed Bragg reflector II of Figure 132.

Figure 134 shows the structure for one period of the p-type semiconductor distributed Bragg

25   reflector I of Figure 132. Referring to Figure 134,

it can be seen that p-AlAs is used for the low

refractive index layer and p-GaAs is used as the high

refractive index layer in the Bragg reflector I.

Further, an intermediate layer (p-AlGaAs linearly

5   graded layer) is provided between these semiconductor

layers with a thickness 60nm. In the semiconductor

distributed Bragg reflector of Figure 132, the

structure of Figure 134 is repeated four times.

Figure 135 shows the structure for one

10   period of the p-type semiconductor distributed Bragg

reflector II of Figure 132. Referring to Figure 135,

it can be seen that p-AlAs is used as a low

refractive index layer and p-GaAs is used as a high

r0efractive index layer in the Bragg reflector II,

15   and an intermediate layer (p-AlGaAs linearly graded

layer) of 30nm thickness is provided between these

semiconductor layers. In the semiconductor

distributed Bragg reflector of Figure 132, the

structure of Figure 135 is repeated for 20 times.

20   Thus, in the thirty-second embodiment, the

thickness of the intermediate layer (compositional

graded layer) is increased in a region I (Bragg

reflector I) of the distributed Bragg reflector as

compared with other region II (Bragg reflector II) in

25   the semiconductor distributed Bragg reflector in

which the intermediate layer (compositional gradated layer) is sandwiched between the first and second semiconductor layers with a refractive index intermediate to the first and second semiconductor
5   layers.

Here, it should be noted that the thickness of each layer forming the Bragg reflector is adjusted so as to satisfy the phase condition of multiple reflection of the distributed Bragg reflector
10   including the intermediate layer (compositional graded layer) in each of Bragg reflectors I and II. More specifically, the thickness of the p-AlAs layer in the Bragg reflector I is set to 12.3nm, and the thickness of the p-GaAs layer in the Bragg reflector
15   I is set to 20.3nm. Further, the thickness of the p-AlAs layer in the Bragg reflector II is set to 51.6nm and the thickness of the p-GaAs layer in the Bragg reflector II is set to 40.9nm.

It should be noted that the p-type
20   semiconductor distributed Bragg reflector of Figure 132 is designed such that the light is incident from the side of the Bragg reflector I and the impurity doping concentration in the region I (Bragg reflector I) is set to about $5 \times 10^{17} cm^{-3}$ such that the impurity
25   doping concentration becomes lower to the impurity

doping concentration in the region II (Bragg
reflector II).

Thus, by setting the impurity doping
concentration to be small in the region I (Bragg
5   reflector I), to which the light comes in and hence
the electric field strength of the light is large,
the problem of conventional technology of optical
loss caused by free carrier absorption or intra-
valence band absorption can be successfully reduced.
10   Further, in the semiconductor distributed
Bragg reflector of Figure 132, it should be noted
that the thickness of the compositional graded layer
is set to 60nm in the region I (Bragg reflector I)
where the doping concentration is relatively low,
15   such that the thickness becomes larger than the
thickness in the region II (Bragg reflector II).

By reducing the impurity concentration
level, there arises the problem of increase of
electrical resistance because of the increased
20   influence of the potential barrier formed at the
heterointerface. In the semiconductor distributed
Bragg reflector of Figure 132, on the other hand, it
becomes possible reduce the potential barrier height
sufficiently, by increasing the thickness of the
25   compositional graded layer in the region I (Bragg

reflector I), in which the doping concentration is relatively low, to a very large value of 60nm. With this, the problem of increase of device resistance, caused by the influence of the heterointerface, which

5   in turn is caused as a result of the use of low impurity doping concentration level, is successfully prevented. Further, as a result of the use of low doping concentration, optical loss of light is reduced, and excellent semiconductor distributed

10 Bragg reflector is obtained with regard to optical as well as electrical properties.

In the present embodiment, the semiconductor distributed Bragg reflector is fabricated by conducting a crystal growth process on

15 a GaAs substrate while using a MOCVD process. However, it is possible to use a different crystal growth process. Further, the present embodiment uses a linearly graded layer for the intermediate layer (the semiconductor layer having an intermediate refractive

20 index (bandgap)) provided between the two semiconductor layers of different kinds having different refractive indices and constituting the semiconductor distributed Bragg reflector. However, it is also possible to use a non-linear graded layer,

25 in which the composition changes non-linear, for the

intermediate layer. Also, it is possible to use a single layer or multiple layers for the intermediate layer, as long as the intermediate layer has a different refractive index.

5   As noted before, there is a problem in a p-type semiconductor distributed Bragg reflector that it easily causes increase of resistance as a result of the effect of potential barrier such as spikes formed at the semiconductor heterointerface, and this

10   problem of increase of resistance becomes conspicuous when the bandgap difference between the semiconductor layers forming the heterointerface is increased or when the doping concentration in the vicinity of the heterointerface is reduced. Conventionally, it has

15   been practiced to increase the doping concentration of the heterobarrier buffer layer provided between the two semiconductor layers of different kind such as the composition graded layer. However, the use of such a high doping concentration causes the problem

20   of increased optical absorption and deteriorated optical characteristics.

          Also, it is effective to reduce the impurity concentration level for reducing the optical absorption, while reduction of the impurity

25   concentration level invites increased influence of

the potential barrier at the heterointerface. In order to reduce the influence of the potential barrier formed at the heterointerface, it is conceivable to reduce the bandgap difference for the two semiconductor layers of different kind constituting the heterointerface. However, such a measure causes a problem in that there is caused decrease of reflectivity of the reflector and it becomes necessary to increase the number of the layers in the Bragg reflector. Further, there is caused increased penetration of the region of large electrical field intensity into the region inside the Bragg reflector, and it becomes necessary to increase the thickness of the low concentration doping region further. However, such an increase of thickness of the low refractive index layer causes problem of increase of resistance. Further, it is difficult to reduce the resistance sufficiently even in the case the bandgap is reduced, unless the compositional graded layer provided at the heterointerface is designed appropriately.

In the case a distributed Bragg reflector is used as the cavity reflector of a surface-emission laser device, and the like, it is generally practiced to provide an oxidation confinement layer formed by

oxidation of Al(Ga)As in the Bragg reflector. Further,
this oxidation confinement layer is generally
provided in a low doping region near the active layer
for increasing the effect of current confinement. It

5   should be noted that the doping concentration is
reduced in the region in the vicinity of the active
layer for minimizing optical absorption. In, the
vicinity of the oxidation confinement layer, however,
there is a tendency of resistance increase also in

10   the case the doping concentration is not reduced
because of the reduced current path caused by
concentration of electric current.

In the case of the semiconductor
distributed Bragg reflector of the thirty-second

15   embodiment of the present invention, on the contrary,
it becomes possible to reduce the resistance of the
aforementioned region which easily undergoes a
resistance increase very effectively, by increasing
the thickness of the low doping region or the

20   thickness of the intermediate layer (compositional
graded layer) provided in the peripheral part of the
oxidation confinement layer relatively with regard to
other regions.

For example, Figure 136 shows the

25   resistance of a semiconductor distributed Bragg

reflector of four pairs designed for the 0.98 μm band as a function of the thickness of the compositional graded layer for various Al contents of the low refractive index layer of the Bragg reflector. Here,

5   the vertical axis represents the resistivity (normalized resistivity) of the Bragg reflector normalized by a resistivity determined simply by a bulk resistance in the case there is no influence of the heterointerface. Thus, in Figure 136, it can be

10   seen that the normalized resistivity gradually approaches to 1 with decrease of the influence of the heterointerface (increasing of thickness of the compositional graded layer). Here, it should be noted that a GaAs layer is used for the high refractive

15   index layer. The doping concentration of the Bragg reflector is set to $5\times10^{17}\text{cm}^{-3}$ throughout so as to reduce the optical absorption.

From Figure 136, it can be seen that, while the resistivity of the semiconductor distributed

20   Bragg reflector decreases by reducing the difference of the Al content with regard to GaAs, the resistivity falls off much more drastically by increasing thickness of the intermediate layer (compositional graded layer).

25   Thus, it will be understood that the

resistance can be reduced sufficiently in the case a
thick compositional graded layer is provided, without
reducing the difference of Al content.

Figure 137 is a diagram showing the
5   relationship between the reflectivity of a p-type
semiconductor distributed Bragg reflectors of 5 pairs
designed for the 0.98μm band and the thickness of
the intermediate layer (compositional graded layer)
for various Al contents of the low refractive index
10   layer that constitutes the Bragg reflector. Here, it
should be noted that the GaAs layer forming the high
refractive index layer has the thickness of 69.5nm,
and the AlAs layer, the $Al_{0.8}Ga_{0.2}As$ layer, the
$Al_{0.6}Ga_{0.4}As$ layer and the $Al_{0.4}Ga_{0.6}As$ layer forming a
15   low refractive index layer have the thickness of
80.2nm, 77.5nm, and 74.8nm, respectively in the
distributed Bragg reflector designed for the
reflection wavelength of 0.98μm in the case here is
provided no compositional graded layer. By reducing
20   the Al content of the low refractive index layer, it
can be seen from Figure 137 that the reflectivity of
the Bragg reflector falls off significantly. Further,
it can be seen from Figure 137 that the influence to
the reflectivity becomes smaller in the case a thick
25   intermediate layer (compositional graded layer)

having a thickness of about 60nm is provided, as compared with the influence caused by the change of the Al content in a low refractive index layer.

Thus, in the semiconductor distributed

5   Bragg reflector of the present embodiment, it is possible to reduce the resistance sufficiently while maintaining the high reflectivity by providing a thick intermediate layer (compositional graded layer), without reducing the Al content of the low refractive

10   index layer to the degree that a large influence is caused on the reflectivity as in the case of the conventional technology, even in the region of low doping density. Further, because of the high reflectivity, it is possible to reduce the

15   penetration of light into the semiconductor distributed Bragg reflector, and the layer number of a low density layers can be reduced. Thereby, the overall resistance of the semiconductor distributed Bragg reflector is reduced. Also, because there is

20   little influence on the reflectivity, there is no need of increasing the number of the layers of the Bragg reflector, and the problem of increase of resistance caused by increase of the number of stacks can be eliminated effectively.

25   In the case of providing an oxidation

confinement layer such as a selective oxidation layer to the region where the thickness of thick of the intermediate layer (compositional graded layer) is increased for current confinement, it is possible to

5   suppress the increase of resistance due to the fact that the resistance is reduced in the region where the current is concentrated as a result of the oxidation confinement.

As noted above, the present embodiment

10   provides a semiconductor distributed Bragg reflector of excellent characteristics in terms of optical and electrical properties, such as reduced optical absorption loss and reduced electric resistance.

In the description heretofore, a p-type

15   distributed Bragg reflector formed of two regions, the distributed Bragg reflectors I and II, in which the thickness and doping concentration of the intermediate layer (compositional graded layer) are changed, as the thirty-second embodiment of the

20   present invention. On the other hand, the p-type distributed Bragg reflector is not limited to the one formed of such two regions but may be formed of three or more regions in which the thickness and doping concentration of the intermediate layer are changed.

25

[Thirty-third embodiment]

In the thirty-third embodiment of the present invention, the semiconductor Bragg reflector has the feature of the thirty-second embodiment

5 explained before and further has the feature that the bandgap difference of the two different semiconductor layers of different refractive indices is reduced in the region where the intermediate layer, provided between the foregoing two semiconductor layers of

10 different kinds, has an increased thickness, as compared with the region where the intermediate layer has a reduced thickness.

Figure 138 is a diagram showing an example of the semiconductor distributed Bragg reflector of

15 the thirty-third embodiment of the present invention. It should be noted that the semiconductor distributed Bragg reflector of Figure 138 is a p-type semiconductor distributed Bragg reflector having a designed reflection wavelength of 0.98μm and is

20 constructed on a GaAs substrate by using an MOCVD process as the crystal growth process.

It should be noted that the semiconductor distributed Bragg reflector of Figure 138 is formed of two regions I, II (Bragg reflectors I, II) in

25 which the thickness of the intermediate layer

(compositional graded layer) is changed. With this regard, the semiconductor distributed Bragg reflector of Figure 138 is similar to the p-type semiconductor distributed Bragg reflector of the thirty-second

5 embodiment. On the other hand, the distributed Bragg reflector of the present embodiment is different from the distributed Bragg reflector of the previous embodiment in the point that the Al content of the low refractive index layer is changed in each of the

10 regions I and II.

Figure 139 shows the construction of the p-type semiconductor distributed Bragg reflector I of Figure 138 for one period, while Figure 140 shows the construction of the p-type semiconductor distributed

15 Bragg reflector II of Figure 138 for one period.

In the example of Figures 139 and 140, it should be noted that p-$Al_{0.8}Ga_{0.2}As$ is used for the low refractive index layer of region I (Bragg reflector I) as shown in Figure 139, while p-AlAs is used for

20 the low refractive index layer of region II (Bragg reflector II) as shown in Figure 140. In each of the regions I and II, a p-GaAs layer is used for the high refractive index layer.

In the Bragg reflector I, an intermediate

25 layer (p-AlGaAs linearly graded layer) of 60nm

thickness is provided at each heterointerface, and an intermediate layer (p-AlGaAs linearly graded layer) of 30nm thickness is provided in the Bragg reflector II at each heterointerface.

5   Here, it should be noted that the thickness of each layer including the intermediate layer (compositional graded layer) constituting the reflector in the Bragg reflectors I and II is adjusted so as to satisfy the phase condition of

10   multiple reflection of a distributed Bragg reflector. More specifically, the thickness of the p-$Al_{0.8}Ga_{0.2}As$ layer in the Bragg reflector I is set to 18.0nm, while the thickness of the p-GaAs layer is set to 11.8nm. Further, the thickness of the p-AlAs layer in

15   the Bragg reflector II is set to 51.6nm while the thickness of the p-GaAs layer is set to 40.9nm.

Further, the semiconductor distributed Bragg reflector of Figure 138 is designed such that the incoming light comes upon the substrate surface

20   located at the side of the region I (Bragg reflector I), and the doping concentration of impurities in the region I (Bragg reflector I) is set relatively lower than the impurity doping concentration in the region II (Bragg reflector II) such as $5 \times 10^{17} cm^{-3}$.

25   In the semiconductor distributed Bragg

reflector of Figures 138, 139 and 140, it should be
noted that the low refractive index layer of the
region I (Bragg reflector I) has the composition of
p-Al$_{0.8}$Ga$_{0.2}$As. Because of the reduced Al content of
5   the low refractive index layer (from AlAs to
Al$_{0.8}$Ga$_{0.2}$As), it becomes possible to suppress the
occurrence of potential barrier at the
heterointerface.

       Generally a mixed crystal of AlGaAs shows
10 the tendency of increased mobility for the holes
forming the carriers when the Al content is decreased.
Thus, it is possible in the Bragg reflector of the
present invention, in which the effect of potential
barrier at the heterointerface is reduced as a result
15 of the use of thick compositional graded layer, to
achieve the reduction of resistance effectively by
way of increasing the mobility. Thus, by reducing
the Al content of the low refractive index layer of
the low doping region to the degree that there occurs
20 no remarkable decrease of the reflectivity, it is
possible to obtain a Bragg reflector in which the
electric resistance is reduced furthermore.

       Thus, in the thirty-third embodiment, too,
it is possible to obtain a semiconductor distributed
25 Bragg reflector having excellent optical and

electrical characteristics such as reduced optical absorption loss and reduced electrical resistance.

In the thirty-third embodiment, the electric resistance can be reduced further, by
5 increasing the thickness of the intermediate layer (compositional graded layer) in a region of the semiconductor distributed Bragg reflector than in other regions and further by reducing the bandgap difference between the two semiconductor layers of
10 different kinds constituting the semiconductor distributed Bragg reflector in the foregoing region.

As mentioned before, the resistance increase at the heterointerface is caused by the potential barrier formed at such a heterointerface,
15 and the resistance becomes higher when the bandgap difference between the semiconductor layers constituting the heterointerface is increased. Further, the resistance increases with decreased doping concentration of the heterointerface. In the
20 case the doping concentration is reduced for semiconductor layer of the Bragg reflector located at the incident side of the light for reducing the optical absorption loss, the influence of the heterointerface becomes conspicuous due to the
25 reduced doping concentration, and the resistance

increases easily. On the other hand, by increasing

the thickness of the intermediate layer

(compositional graded layer) of such a region as

compared to other regions as in the thirty-second

5   embodiment, the electric resistance can be reduced

effectively. Thereby, the reduction of the electrical

resistance can be enhanced further by reducing the

bandgap difference of the semiconductor layers

constituting the semiconductor distributed Bragg

10   reflector.

In the case the semiconductor distributed

Bragg reflector is used as the cavity reflector of a

surface-emission laser diode, and the like, there are

often the cases in which the oxidation confinement

15   layer formed by oxidizing Al(Ga)As is provided in the

semiconductor distributed Bragg reflector. Further,

there are often the cases in which such an oxidation

confinement layer is provided in the low doping

region close to the active layer for enhancing the

20   confinement effect. In the periphery of the oxidation

confinement region, however, it is easily caused the

increase of resistance because of the reduction of

the current path. This problem can be caused also in

the case the doping concentration is not reduced.

25   On the other hand, it is possible to reduce

the electrical resistance in this region drastically
in the semiconductor distributed Bragg reflector of
the thirty-third embodiment, by increasing the
thickness of the intermediate layer (compositional
5   graded layer) for the region where the increase of
resistance occurs very easily, such as the low doping
concentration region or peripheral region of the
oxidation confinement layer. By reducing the bandgap
difference for the semiconductor layers constituting
10   the semiconductor distributed Bragg reflector further,
it becomes possible to reduce the electric resistance
further.

    For example, it becomes possible to reduce
the resistance by reducing the bandgap difference of
15   the semiconductor layers constituting the
semiconductor distributed Bragg reflector in any of
the structures by setting the thickness of the
compositional graded layer to 50nm as shown in Figure
136. Thereby, the electric resistance can be reduced
20   further by reducing the bandgap difference of the
semiconductor layers. Thus, it will be understood
that reduction of the bandgap difference is effective
for further reduction of the electrical resistance.
Because an AlGaAs mixed crystal has the tendency of
25   increasing the mobility of holes with decrease of the

Al content, the abovementioned construction of
reducing the bandgap difference is effective for
reducing the electrical resistance. When the bandgap
difference is reduced excessively, on the other hand,

5   the influence to the reflectivity becomes conspicuous
and penetration of light to the semiconductor
distributed Bragg reflector becomes conspicuous. Thus,
it becomes possible to obtain an excellent
semiconductor distributed Bragg reflector having

10   excellent electric characteristics, by choosing the
Al content of the low refractive index layer such
that the characteristic does not get worse remarkably.

In the thirty-third embodiment, it should
be noted that the semiconductor distributed Bragg

15   reflector can be formed on a GaAs substrate by
conducting a crystal growth process according to an
MOCVD method. On the other hand, it is possible to
use other crystal growth method. In the
abovementioned example, it is noted that a linear

20   compositional graded layer is used as the
intermediate layer provided between two semiconductor
layers of different refractive indices and
constituting the semiconductor distributed Bragg
reflector (semiconductor layer having a refractive

25   index (bandgap) intermediate of the two semiconductor

layers of difference refractive indexes). However, it
is also possible to use a non-linear compositional
graded layer characterized by a non-linear
compositional change for the intermediate layer.
5 Further, it is possible to form the intermediate
layer in the form of single or plural layers of
different refractive indices.

[Thirty-fourth Embodiment]
10   The thirty-fourth embodiment of the present
invention has a feature in that, in the semiconductor
distributed Bragg reflector of the thirty-second or
thirty-third embodiment, the thickness and doping
concentration are changed for the plural intermediate
15 layers (semiconductor layers) inside the
semiconductor distributed Bragg reflector in
correspondence to the electric field strength of the
light.
        More specifically, the thickness is
20 increased and doping concentration is decreased for
the intermediate layer (semiconductor layer) in the
region of the semiconductor distributed Bragg
reflector where the electric field strength of the
light is large in the thirty-fourth embodiment of the
25 present invention. In the region where the electric

field strength is weak, on the other hand, the thickness of the intermediate layer (semiconductor layer) is reduced and the doping concentration is increased.

5   Figure 141 is a diagram showing an example of the semiconductor distributed Bragg reflector of the thirty-fourth embodiment of the present invention. It should be noted that the semiconductor distributed Bragg reflector of Figure 141 is a p-type

10   semiconductor distributed Bragg reflector having a design reflection wavelength of 0.98μm and formed on a GaAs substrate by using an MOCVD process for the crystal growth process.

         The semiconductor distributed Bragg

15   reflector of Figure 141 is formed of two regions I and II, (two Bragg reflectors I and II) characterized by different thickness for the intermediate layer (compositional graded layer), similarly to the p-type semiconductor distributed Bragg reflector of the

20   thirty-second embodiment, except that, in the thirty-fourth embodiment, the thickness and the impurity doping concentration of the intermediate layer (compositional graded layer) in the region I and the thickness and the impurity concentration of the

25   intermediate layer (compositional graded layer) in

the region II are changed in correspondence to the electric field strength of the light. Thereby, the thickness of each layer constituting the semiconductor distributed Bragg reflector is adjusted

5 so as satisfy the phase condition of multiple reflection of the semiconductor distributed Bragg reflector, including the intermediate layer (compositional graded layer).

In more detail, the semiconductor

10 distributed Bragg reflector of Figure 141 is designed such that the incoming light comes upon the substrate surface at the side of the region I (Bragg reflector I), and p-$Al_{0.8}Ga_{0.2}As$ is used as the low refractive index layer and p-GaAs is used as a high refractive

15 index layer in the region I (Bragg reflector I), as shown in Figure 142. It should be noted that Figure 142 is the diagram showing the construction of the semiconductor distributed Bragg reflector in region I. It can be seen that the semiconductor distributed

20 Bragg reflector I is formed of five times repetition of the fundamental structure shown in Figure 142, wherein the fundamental structure is formed of one pair of p-GaAs/p-$Al_{0.8}Ga_{0.2}As$ layers and two compositional graded layers provided adjacent to the

25 respective layers. It should be noted that Figure 142

is a diagram showing the foregoing fundamental structure repeated twice for the purpose of illustrating the change of thickness of the compositional graded layer in the semiconductor

5   distributed Bragg reflector of Figure 141.

Figure 143 is a diagram showing the construction of the region II in the semiconductor distributed Bragg reflector of Figure 141. As shown in Figure 143, it can be seen that $p-Al_{0.8}Ga_{0.2}As$ is

10 used as the low refractive index layer in the region II (Bragg reflector II) and p-GaAs is used as the high refractive index layer. It should be noted that Figure 143 is the diagram showing the fundamental structure in the region II (Bragg reflector II). As

15 can be seen in Figure 143, there is provided an intermediate layer (compositional graded layer) of 30nm thickness between p-AlGaAs and p-GaAs layer in the region II. In Figure 141, the fundamental structure of Figure 143 is repeated for 20 times.

20 Here, it should be noted that an intermediate layer (compositional graded layer) of 30nm thickness is provided in the region II (Bragg reflector II) at each heterointerface.

Further, the impurity doping concentration

25 in the $Al_{0.8}Ga_{0.2}As$ layer and the GaAs layer of the

region II (Bragg reflector II) is set to about

$1 \times 10^{18} cm^{-3}$. Thus, by setting the doping concentration

of the intermediate layer (compositional graded

layer) to be generally equal to or slightly higher

5   than the foregoing doping concentration, effective

reduction of resistance becomes possible.

On the other hand, the doping concentration

of the intermediate layer (compositional graded

layer) in the region I (Bragg reflector I) is

10   adjusted such that the doping concentration increases

gradually from the surface where the electric field

strength of the light is large toward the substrate

(in the direction of arrow R of Figure 141 or 142,

and in correspondence to this, the thickness of the

15   intermediate layer (compositional graded layer) is

decreased gradually in the direction of arrow R of

Figure 141 or 142 from the surface to the substrate.

In more detail, the doping concentration at

the surface side is set to $5 \times 10^{17} cm^{-3}$ in region I

20   (Bragg reflector I), for example, and the doping

concentration is adjusted such that it increases

gradually toward the substrate (toward the doping

concentration of the region II (Bragg reflector II)).

Further, the thickness of the intermediate layer

25   (compositional graded layer) is adjusted to decrease

gradually from the value of 60nm at the surface side toward the substrate (toward thickness of 30nm of the Bragg reflector II).

More specifically, an intermediate layer
5 (compositional graded layer) of 60nm thickness is provided to the heterointerface of the outermost surface of the region I (Bragg reflector I), and the $p-Al_{0.8}Ga_{0.2}As$ layer and the p-GaAs layer that sandwiching this intermediate layer (compositional
10 graded layer) have respective thickness of 18.0nm and 11.8nm. Further, the thickness of the intermediate layer (compositional graded layer) in the region I (Bragg reflector I) is changed with the doping concentration in the direction toward the region II
15 (Bragg reflector II) such that the thickness gradually decreases from the thickness of 60nm to the thickness of 30nm, which is the thickness of the intermediate layer (compositional graded layer) of the region II (Bragg reflector II). Along with this,
20 the film thickness of the $p-Al_{0.8}Ga_{0.2}As$ layer, p-GaAs layer are gradually increased. Here, it should be noted that the thickness of the $p-Al_{0.8}Ga_{0.2}As$ layer in the region II (Bragg reflector II) is set to 51.6nm and the thickness of the p-GaAs layer is set to
25 40.9nm.

In the semiconductor distributed Bragg
reflector of the thirty-fourth embodiment, the
impurity doping concentration is reduced in the
region where the electric field strength of the

5   incoming light is large. Further, the thickness of
the intermediate layer (compositional graded layer)
is chosen so as to prevent the increase of resistance
as a result of the decrease of the impurity doping
concentration (thickness of thick of the intermediate

10   layer is increase). As a result, it becomes possible
to obtain a Bragg reflector having excellent optical
and electric characteristics such as efficiently
reduced absorption loss, without increasing the
resistance unnecessarily without decreasing the

15   reflectivity in the region I (Bragg reflector I).
          Thus, the semiconductor distributed Bragg
reflector of the thirty-fourth embodiment includes
plural intermediate layers (compositional graded
layers) in the Bragg reflector with different

20   thickness determined according to the electric field
strength of the light incident to the semiconductor
distributed Bragg reflector. Further, the doping
concentration of the compositional graded layer is
changed according to the electric field strength of

25   the light incident to the semiconductor distributed

Bragg reflector (More specifically, the thickness of the compositional graded layer is increased and the doping concentration is reduced in the region where the electric field strength is large. The thickness

5   of the compositional graded layer is decreased and the doping concentration is increased in the region where the electric field strength is weak). With this, it becomes possible to reduce the optical absorption loss efficiency with the electric field strength

10 inside the semiconductor distributed Bragg reflector, together with the resistance.

In a semiconductor distributed Bragg reflector, the thickness of each semiconductor layer is chosen so as to satisfy the phase condition in

15 which the light waves strengthen with each other, such that the reflection waves strengthen with other as a result of multiple reflection of the light caused by the difference of refractive index of the semiconductor layers. Here, it should be noted that

20 the reflection of light wave is caused not only by the surface reflection as in the case of simple reflector but undergoes multiple reflections as it penetrates inside the semiconductor distributed Bragg reflector. Thereby, the electric field strength of

25 light is stronger at the incident surface.

Thus, it becomes possible to reduce the optical absorption loss and the electric resistance effectively by reducing the doping concentration of the semiconductor distributed Bragg reflector in the region where the electric field strength of the light is large according to the electric field of the light and by determining the thickness of the compositional graded layer with the doping concentration such that sufficiently low resistance is achieved. By determining the impurity doping concentration according to the electric field strength of the light as such, the problem of unnecessarily decreasing the doping concentration in the low doping concentration region provided for reducing the increase of optical absorption is eliminated, and it becomes possible to eliminate unnecessary increase of resistance or decrease of the reflectivity caused by providing a compositional graded layer.

However, it is important also in the thirty-fourth embodiment to provide a sufficiently thick compositional graded layer in the region close to the surface where the electric field strength of the light is large in view of the need of reducing the doping concentration sufficiently.

In the case of using the semiconductor

distributed Bragg reflector as the cavity reflector
of a surface-emission laser diode, and the like,
there are many cases in which the oxidation
confinement layer formed by oxidizing Al(Ga)As is
5   provided in the Bragg reflector. Further, such an
oxidation confinement layer is tend to be provided in
the low density doping region close to the active
layer for enhancing the confinement effect. On the
other hand, it is easily caused increase of
10   resistance as a result of the current path becoming
small in the periphery of the oxidation confinement
region.

Thus, there is a problem that there is
caused increase of resistance in the vicinity of the
15   oxidation confinement layer due to the fact that the
current path is reduced as a result of the
confinement and due to the fact that the doping
density is reduced. When the thickness of the
compositional graded layer is increased sufficiently
20   in such a region as compared with other regions as in
the case of the thirty-fourth embodiment, on the
other hand, it becomes possible to suppress the
increase of resistance due to the fact that the
resistance of the region where there occurs current
25   concentration as a result of the current confinement,

is reduced sufficiently.

By increasing the thickness of the intermediate layer (compositional graded layer) in the region of low doping concentration or in the region in which the resistance easily increases such as the peripheral region of the oxidation confinement layer as noted above, the resistance of the Bragg reflector can be reduced very effectively. Accordingly, in this thirty-fourth embodiment of the present invention, an excellent semiconductor distributed Bragg reflector having excellent optical and electrical characteristic is obtained.

In the thirty-fourth embodiment, a semiconductor distributed Bragg reflector was explained for the case the thickness of the intermediate layer is gradually decreased and the doping concentration of the intermediate layer is gradually increased from the incident side of the light with the electric field strength of the light as an example of the semiconductor distributed Bragg reflector in which the thickness and the doping concentration are changed. In the semiconductor distributed Bragg reflector of the thirty-second and thirty-third embodiments formed of two regions of different thickness for the intermediate layer, it is

noted that the doping concentration is reduced in the region where the intermediate layer has an increased thickness and the doping concentration is increased in the region where the intermediate layer has a
5   reduced thickness. Even in these cases, it is possible to reduce the optical absorption loss and electrical resistance effectively.

        In the thirty-fourth embodiment, it should be noted that the semiconductor distributed Bragg
10   reflector is formed on a GaAs substrate by carrying out the crystal growth by an MOCVD process. However, other growth process may also be used. Further, while the foregoing example uses a linear compositional graded layer for the intermediate layer between the
15   two semiconductor layers of that different refractive indices (semiconductor layer having a refractive index (bandgap) intermediate of the refractive indices of the two semiconductor layers of different refractive indices) and constituting the
20   semiconductor distributed Bragg reflector, it is also possible to use a non-linear compositional graded layer in which the refractive index changes non-linear for the intermediate layer. Further, it is possible to form the intermediate layer from single
25   or plural layers having different refractive indices.

[Thirty-fifth Embodiment]

In a thirty-fifth embodiment of the present invention, the semiconductor distributed Bragg

5   reflector has a designed reflection wavelength longer than 1.1 μm in the semiconductor distributed Bragg reflectors of the any of thirty-second through thirty-fourth embodiment.

Figure 144 is a diagram showing an example
10   of the semiconductor distributed Bragg reflector according to a thirty-fifth embodiment of the present invention. It should be noted that the semiconductor distributed Bragg reflector of Figure 144 is a p-type semiconductor distributed Bragg reflector having a
15   design reflection wavelength of 1.3 μm band and formed on the GaAs substrate by using an MOCVD process as the crystal growth process.

Further, it should be noted that the semiconductor distributed Bragg reflector of Figure
20   144 is formed of two regions I and II characterized by different thickness of the intermediate layer (compositional graded layer), similarly to the p-type semiconductor distributed Bragg reflector of the thirty-second embodiment.

25   Figure 145 shows one period of the Bragg

reflector I of Figure 144. Referring to Figure 145,
it should be noted that p-Al $_{0.8}$Ga$_{0.2}$As is used as the
low refractive index layer and p-GaAs is used as the
high refractive index layer in the p-type

5   semiconductor distributed Bragg reflector I. Further,
an intermediate layer (p-AlGaAs linear compositional
graded layer) of 80nm thickness is provided to each
of these semiconductor layers. In the semiconductor
distributed Bragg reflector of Figure 144, the

10   construction of Figure 145 is repeated four times.

Similarly, Figure 146 shows one period of
the stacks in the p-type semiconductor distributed
Bragg reflector II of Figure 144. In the Bragg
reflector II, p-AlAs is used for low refractive index

15   layer and p-GaAs is used for the high refractive
index layer. Further, an intermediate layer (p-AlGaAs
linear compositional graded layer) of 50nm thickness
is provided to each of the interfaces of these
semiconductor layers, and the semiconductor

20   distributed Bragg reflector of Figure 144 is repeated
twenty times in the construction Figure 146.

The semiconductor distributed Bragg
reflector of Figure 144 is designed such that
incident light comes from the side of the region I

25   (Bragg reflector I) where there exists a substrate

surface, and the impurity doping concentration in the region I is set to be lower than the doping concentration in the region II, such as $5 \times 10^{17} cm^{-3}$.

It should be noted that the design

5   reflection wavelength of the semiconductor distributed Bragg reflector of Figure 144 is set to the long wavelength band of $1.3 \mu m$, which is longer than the design wavelength of the conventional Bragg reflector of the $0.98 \mu m$ band. In such a long

10   wavelength band, it is known that there occurs remarkable optical absorption caused by intra-valence band transition. For example, reference should be made to IEEE J. Quantum Electron, Vol. 33, No. 8, 1997, pp. 1369. This reference describes that the

15   optical absorption coefficient of GaAs to a light of the $1.3 \mu m$ band is about twice as large as in the case of the $0.98 \mu m$ band and that the optical absorption coefficient becomes about three times as large as in the case of the $0.98 \mu m$ band for the

20   light of the $1.5 \mu m$ band. Thus, the effect of optical absorption becomes very conspicuous for the light of the wavelength longer than $1.1 \mu m$, and it becomes very important to reduce the optical absorption for realizing a highly efficient semiconductor

25   distributed Bragg reflector.

In the semiconductor distributed Bragg
reflector of Figure 144, the doping concentration of
the region I constituting the incident side of the
light is set to relatively low concentration, and the
5   optical absorption losses is reduced in this region.
Further, because of the increased reflection
wavelength, the thickness of the layers constituting
the semiconductor distributed Bragg reflector is set
larger than the case of the conventional surface-
10   emission laser of the 0.98μm band. Because of this,
the influence to the decrease of the reflectivity is
greatly reduced even in the case a thick intermediate
layer (compositional graded layer) is provided.
Further, as a result of use of the thick intermediate
15   layer (compositional graded layer), the effect of
smoothing the potential barrier at the
heterointerface is enhanced significantly. Thus, the
effect of reducing the electric resistance by the
intermediate layer (compositional graded layer) is
20   significant even in the case the bandgap difference
between the two different semiconductor layers
constituting the semiconductor distributed Bragg
reflector is large. Thus, the penetration of the
light into the semiconductor distributed Bragg
25   reflector is suppressed effectively, and it becomes

possible to reduce the thickness of the low doping

region. Further, the number of the layers in the

semiconductor distributed Bragg reflector can be

reduced and the electrical resistance is suppressed

5   effectively.

Thus, in the thirty-fifth embodiment, it is

possible to obtain a semiconductor distributed Bragg

reflector showing excellent characteristics such as

reduced optical absorption losses and reduced

10   electrical resistance in the long-wavelength band.

In more detail, the intra-valence band

absorption, which becomes the major cause of the

optical absorption in a p-type semiconductor

distributed Bragg reflector, is caused as a result of

15   the electrons absorbing the light and causing

transition from the spin orbital split-off band in

the valence band to the heavy hole band or and light

hole band. Because of the small difference of energy

between these levels, the absorption becomes

20   conspicuousness for the light having a long

wavelength. Thus, the laser devices formed on a GaAs

substrate shows a conspicuous optical absorption loss

in the wavelength band of 1.3μm or 1.5μm, which is

important for optical telecommunication, and the like,

25   as compared with the light of 0.85μm band or 0.98μm

band. Thus, it is difficult to obtain excellent p-
type semiconductor distributed Bragg reflector of the
characteristics of low resistance and simultaneously
small optical absorption by the conventional

5   technology because of the large absorption
coefficient in the p-type semiconductor distributed
Bragg reflector.

        In the construction of any of the thirty-
second through thirty-fourth embodiments of the

10   present invention, on the other hand, it is possible
to reduce the optical absorption of in region showing
conspicuous optical absorption, in other words the
region inside the semiconductor distributed Bragg
reflector characterized by large strength of the

15   light, without increasing the resistance, as
mentioned before. In the case the semiconductor
distributed Bragg reflector of the thirty-fifth
embodiment is constructed to have the reflection
wavelength of the long wave even from the 1.1μm while

20   using a structure not provided with the compositional
graded layer of the 1.3μm band, it should be noted
that the GaAs layer used for the high refractive
index layer and the AlAs layer used for the low
refractive index layer have large thickness of 95.2nm

25   and 111.6nm respectively as a result of the increase

of the design wavelength. Longer the reflection
wavelength, the proportion of the compositional
graded layer in the semiconductor distributed Bragg
reflector is reduced, and the effect on the

5   reflectivity is reduced correspondingly. This means
that it becomes possible to provide a thicker
compositional graded layer than in the case of the
conventional semiconductor distributed Bragg
reflector of the 0.85μm band or the 0.98μm band

10 while maintaining the reflectivity. Thicker the
compositional graded layer, the effect of smoothing
the potential barrier at the heterointerface is high
increased, and becomes of this, it becomes possible
to reduce the electric resistance sufficiently.

15   Figure 147 is a diagram showing the
relationship between the reflectivity and the
thickness of the compositional graded layer for the
semiconductor distributed Bragg reflectors of 5 pairs
and having the reflection wavelength of 1.3μm, for

20 various Al contents of the low refractive index layer.
In Figure 147, it should be noted that GaAs is used
as the high refractive index layer of the
semiconductor distributed Bragg reflector. On the
other hand, the thickness of the AlAs layer, the

25 $Al_{0.8}Ga_{0.2}As$ layer, the $Al_{0.6}Ga_{0.4}As$ layer and the

$Al_{0.4}Ga_{0.6}As$ layer are set respectively to 111.6nm,
108.2nm, 104.8nm and 101.5nm for the case the
composition gradated layer is not provided. Further,
the GaAs layer used for the high refractive index

5   layer has the thickness of 95.2nm as noted above.
Referring to Figure 147, it can be seen that the
influence to the reflectivity is relatively small
even in the case a thick compositional graded layer
is provided as in the case of the semiconductor

10   distributed Bragg reflector of the $0.98\mu m$ band.

Thus, in such a semiconductor distributed
Bragg reflector having a reflection wavelength in the
long wavelength band, the influence of the
compositional graded layer to the reflectivity is

15   reduced as compared with the conventional
semiconductor distributed Bragg reflector of the 0.98
μm band, and it become possible to maintain a high
reflectivity in the lower doping region and the
penetration of light into the semiconductor

20   distributed Bragg reflector is easily reduced.

Thus, it becomes possible in the
semiconductor distributed Bragg reflector of the
thirty-fifth embodiment to reduces the number of the
layers of the low doping region. Because the Bragg

25   reflector as a whole has low resistance and the

reflectivity in the low doping region is sufficiently
high, there is no need of increasing the number of
the layers in the semiconductor distributed Bragg
reflector, and the overall resistance of the Bragg

5   reflector can be suppressed similarly.

Thus, the effect of decrease of the
resistance appears particularly conspicuously in the
semiconductor distributed Bragg reflector having the
wavelength of the 1.1μm band or longer.

10   As noted before with reference to the
thirty-second through thirty-fourth embodiments,
there are many cases in which an oxidation
confinement layer, formed by oxidizing a Al(Ga)As
layer, is provided in the Bragg reflector when the

15   Bragg reflector is used as the cavity reflector of a
surface-emission laser diode, and the like. Further,
there are many cases in which the oxidation
confinement layer is provided in the low doping
region near the active layer in order to enhance the

20   confinement effect. By increasing the thickness of
the compositional graded layer in the periphery of
the oxidation confinement layer as compared with
other regions, it becomes possible to suppress the
increase of the resistance because of the fact that

25   the resistance of the region where there occurs

current concentration is sufficiently reduced.

As noted above, it is possible to obtain a semiconductor distributed Bragg reflector having a low resistance and small optical absorption loss

5 simultaneously in the semiconductor distributed Bragg reflector of the type in which an intermediate layer is provided between two semiconductor layers of different refractive indices with a refractive index intermediate of the two semiconductor layers without

10 sacrificing the reflectivity, by setting the thickness of the intermediate layer such that thickness of the intermediate layer is different in a region of the semiconductor distributed Bragg reflector from other regions of the semiconductor

15 distributed Bragg reflector.

As noted above, the thirty-fifth embodiment of the present invention provides a semiconductor distributed Bragg reflector showing excellent optical and electrical characteristics such as sufficiently

20 low optical absorption loss and sufficiently low electric resistance in the long-wavelength band (reflection wavelength longer than 1.1μm).

In the thirty-fifth embodiment, the semiconductor distributed Bragg reflector was formed

25 on a GaAs substrate by carrying out a crystal growth

by the MOCVD process. However, it is possible to use other growth processes such as MBE process, and the like. While a linear compositional graded layer is used in an abovementioned for the intermediate layer

5　provided between the two semiconductor layers of different refractive indices and constituting the semiconductor distributed Bragg reflector (semiconductor layer having an intermediate refractive index (bandgap) of the refractive indices

10　of the foregoing two semiconductor layers of different refractive indices), it is also possible to use a non-linear compositional graded layer in which the composition changed non-linear for the intermediate layer.

15

[Thirty-sixth Embodiment]

　　　By using the semiconductor distributed Bragg reflectors of any of the first through thirty-fifth embodiments explained above, it is possible to

20　construct a surface-emission laser diode.

　　　Thus, the thirty-sixth embodiment of the present invention provides a surface-emission laser diode that uses the semiconductor distributed Bragg reflectors of any of the first through thirty-fifth

25　embodiments for the cavity reflector.

Figure 148 is a diagram showing an example of the surface-emission laser diode of the thirty-sixth embodiment.

The surface-emission laser diode of Figure
5   148 is a surface-emission laser device of the 1.3μm band and has an active layer of GaInNAs. The laser diode is fabricated by carrying out a crystal growth by an MOCVD process using trimethyl aluminum (TMA), trimethyl gallium (TMG), trimethyl indium (TMI) and
10   an arsine (AsH$_3$) gas as the source materials. Further, dimethylhydrazine (DMHy) is used for the nitrogen source material when forming the active layer. Further, H$_2$Se was used for the n-type dopant and CBr$_4$ was used for the p-type dopant.

15   Thus, the surface-emission laser diode of Figure 148 is formed on an n-GaAs substrate after forming an n-GaAs buffer layer, by consecutively forming an n-type semiconductor distributed Bragg reflector including 36 pairs of AlAs/GaAs, a GaAs
20   cavity spacer layer, a GaInNAs/GaAs multiple quantum well structure (active layer), a GaAs cavity spacer layer, and a p-type semiconductor distributed Bragg reflector.

Here, it should be noted that the p-type
25   semiconductor distributed Bragg reflector is formed

of a p-type semiconductor distributed Bragg reflector
I (region I) including therein four pairs of
$Al_{0.8}Ga_{0.2}As$/GaAs and a p-type semiconductor
distributed Bragg reflector II (region II) including
5   therein 18 pairs of $Al_{0.8}Ga_{0.2}As$/GaAs. Further, doping
is achieved for the Bragg reflector I (region I)
located near the active layer where the laser
oscillation takes place and the light electric field
strength is large, to the level of $5 \times 10^{17} cm^{-3}$, which
10   is relatively lower than the doping concentration of
the Bragg reflector II of $1 \times 10^{18} cm^{-3}$, such that the
absorption loss of the oscillation light is reduced.

        Further, there is provided a linear
compositional graded layer (intermediate layer) of
15   80nm thickness that changes the Al content linearly
from the side of a semiconductor layer to the side of
another semiconductor layer, to each of the
heterointerfaces of the p-type semiconductor
distributed Bragg reflector I (region I). Further, a
20   linear compositional graded layer (intermediate
layer) of 50nm thickness is provided to each of the
heterointerfaces of the p-type semiconductor
distributed Bragg reflector II (region II).

        In the surface-emission laser diode of the
25   long wavelength such as the $1.3 \mu m$ band, it is

possible to provide a thick compositional graded layer (intermediate layer) like this, without decreasing the reflectivity significantly.

5 Also, in the surface-emission laser diode of Figure 148, there is provided an AlAs selective oxidation layer of 30nm thickness in the p-type semiconductor distributed Bragg reflector I (region I) at the interface at the location of first pair from the active layer. Also, the GaAs layer at the

10 outermost surface of the p-type semiconductor distributed Bragg reflector has an increased doping concentration and functions also as a contact layer.

The thickness of each layer constituting the p-type semiconductor distributed Bragg reflector

15 and the n-type semiconductor distributed Bragg reflector is adjusted so as to satisfy the phase condition of multiple reflection of the distributed Bragg reflector, including the compositional graded layer (intermediate layer), similarly to the thirty-

20 second embodiment. Further, the thickness of the $Al_{0.8}Ga_{0.2}As$ layer adjacent to the AlAs selective oxidation layer is adjusted similarly. Thus, there is formed a λ cavity. The active layer is formed at the center of the λ cavity where is placing the anti-

25 node of standing wave of lasing light.

        The surface-emission laser diode of Figure
148 is produced, after the stacked structure (device
stacking film) noted above is formed, as follows.

        After the formation of the aforementioned

5   stacked structure, an etching process is applied to
each of the layers starting from the surface of the
p-type GaAs contact layer up to the midway of the
GaAs cavity spacer layer adjacent to the n-type
semiconductor distributed Bragg reflector, by

10   carrying out known photolithographic process and dry
etching process so as to leaving a region that
becomes the device region. Thereby, a mesa region is
formed as the device region in the square form having
the size of 30$_{\pi}$m × 30$_{\pi}$m.

15   Next, a heating process is conducted in the
atmosphere that was obtained by bubbling a heated
pure water with nitrogen gas, and selective oxidation
process is conducted laterally from the etching
sidewall of the AlAs selective oxidation layer toward

20   the interior of the device, and a current confinement
structure is formed. Here, the region that becomes a
current path is formed to have the size of 5$_{\pi}$m×5$_{\pi}$m.

        Next, the mesa part is buried by an
insulation resin such as polyimide, and the like, and

25   a p-type electrode having an opening for the laser

output is formed at the top part of the device by using an evaporation process of an electrode material and a lift off process. Further, by forming an n-type electrode at the rear surface of the GaAs substrate, the surface-emission laser diode of Figure 148 is obtained.

In the surface-emission laser diode of Figure 148, it should be noted that the doping concentration of the p-type semiconductor distributed Bragg reflector is reduced particularly in the region near active layer where the intensity of the oscillation light is large. With this, the optical absorption loss is reduced and the slope efficiency of the device is improved. Thereby, the oscillation threshold current is reduced. Further, by increasing the thickness of the intermediate layer (compositional graded layer) in the p-type Bragg reflector I (region I) as compared with the intermediate layer (compositional graded layer) in the p-type Bragg reflector II (region II), the potential barrier at the heterointerface is sufficiently smoothed in spite of the fact that the doping concentration is reduced, and increase of resistance and operational voltage is prevented successfully. Thus, there occurs no increase of heat

generation for the device, and there occurs no
degradation of output as a result of the heat
generation. Because of the decrease of the optical
absorption loss, the device can provide higher output
5   as compared with the conventional case.

It should be noted that the surface-
emission laser diode of Figure 148 uses GaInNAs for
the active layer. Thus, it is possible to form a
surface-emission laser diode oscillating at the
10   wavelength of $1.3\,\mu$m by using the high-performance
semiconductor distributed Bragg reflector formed of
the Al(Ga)As/GaAs layers on the GaAs substrate. As
for the GaInNAs mixed crystal, it should be noted
that there exists a large conduction band
15   discontinuity with regard to the GaAs cavity spacer
layer, and the stable laser oscillation achieved up
to high temperature because of the increased
confinement effect of the electrons in the active
layer. As the $1.3\,\mu$m band corresponds to the zero
20   dispersion band of a silica single mode fiber, a high
speed communication becomes possible by using a
single mode fiber. Thus, the surface-emission laser
diode of Figure 148 can realize a high speed
telecommunication system easily by being combined
25   with a silica single mode fiber.

          In the examples noted above, the surface-

emission laser diode was explained as being produced

by conducting a crystal growth process on an n-type

semiconductor substrate. However, it is also possible

5   to produce a surface-emission laser diode by

conducting a crystal growth process on a p-type

semiconductor substrate.

          Figure 149 shows a surface-emission laser

diode produced by conducting a crystal growth process

10   on a p-type semiconductor substrate. The surface-

emission laser diode of Figure 149 is produced by

conducting the crystal growth process on the p-GaAs

substrate by an MOCVD process similarly to the case

of the surface-emission laser diode of Figure 148.

15   Thus, the surface-emission laser diode of

Figure 149 is produced, after conducting the crystal

growth of the p-GaAs buffer layer on the p-GaAs

substrate, by conducting the crystal growth of the p-

type semiconductor distributed Bragg reflector II

20   (region II) such that an $Al_{0.8}Ga_{0.2}As/GaAs$ structure is

repeated 32 times. Next, the crystal growth of the p-

type semiconductor distributed Bragg reflector I

(region I) is conducted by repeating the

$Al_{0.5}Ga_{0.5}As/GaAs$ structure for five times. Further,

25   the crystal growth of the GaAs cavity spacer layer,

the GaInNAs/GaAs multiple quantum well active layer,
the GaAs spacer layer are conducted, and the crystal
growth of the n-type semiconductor distributed Bragg
reflector is conducted by repeating the

5   $Al_{0.8}Ga_{0.2}As$/GaAs structure for 24 times.

In the surface-emission laser diode of
Figure 149, there is provided a linear compositional
graded layer (intermediate layer) of 50nm thickness
at each heterointerface of the p-type semiconductor

10 distributed Bragg reflector II (region II) for
reducing the electric resistance similarly to the
surface-emission laser diode of Figure 148. Further,
there is provided a linear compositional graded layer
(intermediate layer) of 80nm thickness at each

15 heterointerface of the p-type semiconductor
distributed Bragg reflector I (region I), to satisfy
the multiple reflection condition of the
semiconductor distributed Bragg reflector.
Further, an AlAs selective oxidation layer is

20 provided to the heterointerface of $Al_{0.8}Ga_{0.2}As$/GaAs
nearest to the active layer so as to satisfy the
phase condition.

The surface-emission laser diode of Figure
149 is subjected to the dry etching process,

25 selective oxidation process, burying process by an

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insulating resin, and electrode formation process
after the crystal growth process, similarly to the
surface-emission laser diode of Figure 148. In order
to cause oxidation in the AlAs selective oxidation
5   layer formed in the p-type semiconductor distributed
Bragg reflector, it should be noted that the dry
etching process is carried out such that the etching
reaches the midway of the p-type semiconductor
distributed Bragg reflector.

10   In the surface-emission laser diode of
Figure 149, too, the oscillation (lasing) threshold
current is reduced and the slope efficiency is
improved as a result of the decrease of the optical
absorption loss of the p-type semiconductor
15   distributed Bragg reflector, similarly to the
surface-emission laser diode of Figure 148. Because
of the elimination of increase of the device
resistance, the operational voltage is reduced and
high output power becomes possible.

20   Also, the surface-emission laser diode of
Figure 149 can realize a high speed telecommunication
system easily by being combined with a silica single
mode fiber.

            Thus, in the surface-emission laser diode
25   of the thirty-sixth embodiment, it becomes possible

to reduce the absorption loss of the light and
improve the slope efficiency and reduce the
oscillation threshold current by reducing the doping
concentration of the p-type semiconductor distributed

5   Bragg reflector in the region close to the active
layer where the electric field intensity of the
oscillation light is large, with respect region the
region away from the active layer, and hence, the
electric field intensity of the oscillation light is

10   relatively small.

In the present invention, the potential
barrier at the heterointerface in the low doping
region of a p-type Bragg reflector is smoothed
sufficiently by increasing the thickness of the

15   compositional graded layer in the low doping region
as compared with the high doping region. Thereby, it
becomes possible to reduce the optical absorption
loss without increasing the resistance. Thereby, it
should be noted that the influence caused in the

20   reflectivity is small even when the thickness of the
compositional graded layer is increased sufficiently
as in the case of Figure 137. Thus, it is possible to
provide a sufficiently thick compositional graded
layer. Thus, it is no longer necessary to decrease

25   the Al content significantly in the low concentration

region as is practiced in the conventional art for
reducing the electrical resistance, and it is
possible to maintain high reflectivity in the region
where the doping concentration is low. Thus,

5 diffusion of light into the Bragg reflector is
reduced and the thickness of the low doping region is
reduced, and as a result, increase of the resistance
is successfully eliminated. Further, the stacking
number of the Bragg reflector is reduced and the

10 increase of the resistance is successfully prevented.

In a surface-emission laser diode, there
are many cases that an oxidation confinement layer
formed by oxidizing Al(Ga)As is provided in the
semiconductor distributed Bragg reflector. Further,

15 there are many cases in which the oxidation
confinement layer is provided in the low doping
region close to the active layer in order to increase
the confinement effect. In the periphery of the
oxidation confinement layer, there is a problem that

20 resistance increases easily even in the case the
doping concentration is not reduced due to the
decrease of the current path by current confinement.

On the other hand, by increasing the
thickness of the compositional graded layer in the

25 low doping concentration region or the peripheral

region of the oxidation confinement layer where there
occurs increase of the resistance easily with respect
to other regions, it is possible to decrease the
resistance of the region very effectively as in the
5   example of the semiconductor distributed Bragg
reflector of the present invention.

Thus, it becomes possible to reduce the
operation voltage and device heat generation as
compared with a conventional device, and it becomes
10   possible to obtain a surface-emission laser diode
characterized by reduced oscillation threshold
current and improved slope efficiency and increased
saturation output power as a result of reduced
optical absorption loss.

15   Thus, the surface-emission laser diode of
the thirty-sixth embodiment has the advantageous
characteristics in that the optical absorption loss
of the oscillation light inside the surface-emission
laser diode is reduced, the slope efficiency is
20   improved, the oscillation threshold current is
reduced, a higher output operation is enabled, and
the electric power transformation efficiency is
improved, without increasing the device resistance.

In the surface-emission laser diode of the
25   thirty-sixth embodiment, it is possible to use any or

all of Ga and In for the group III material of the active layer and any or all of As, N and Sb for the group V material of the active layer.

The active layer formed of these materials

5　can be grown on the GaAs substrate by a crystal growth process, and it is possible obtain a surface-emission laser diode that uses a DBR of the AlGaAs material system, which has excellent characteristics with regard to reflectivity, thermal conductivity,

10　process controllability (crystal growth, selective oxidation of the Al(Ga)As mixed crystal, and the like). Further, by using these materials for the active layer, it is possible to obtain the oscillation light not only in the 0.85μm band, 0.98

15　μm band but also in the longer wavelength band, including the 1.1μm band, 1.3μm band and 1.5μm band, which are important in the optical-fiber telecommunication.

By combining the surface-emission laser

20　diode of the 1.3μm band with a silica single mode optical fiber, for example, it is possible to realize high speed optical telecommunication. Further, it is possible to realize a large capacity communication by using the technology of DWDM by the device of the 1.5

25　μm band.

Here, it should especially be noted that, among the various materials of the active layer noted above, the GaInN(Sb)As mixed crystal material can realize the oscillation wavelength of 1.1μm or
5   longer when used for active layer material that mentioned above. Further, a GaInN(Sb)As layer provides a large band discontinuity at the conduction band with respect to the GaAs layer that acts as a carriers confinement layer. Thus, the overflow of
10   electrons is reduced and it becomes possible to obtain a stable laser oscillation up to high temperatures.

In addition to these, the surface-emission laser diode of the present invention has the
15   advantageous feature in that the slope efficiency is improved because of the smaller optical absorption loss and lower resistance as compared with a conventional device as noted above, and can reduce the oscillation threshold current. Further, because
20   of the low resistance, the saturation output power is increased and a high output power is obtained. Further, the electric power transformation efficiency is high, and the electric power consumption is low. As noted above, it is possible to provide a surface-
25   emission laser diode suitable for optical

telecommunication and optical transmission.

In each of the aforementioned embodiments, explanation was made for the case an AlGaAs mixed crystal is used as the material of the semiconductor

5   distributed Bragg reflector. On the other hand, it is also possible to use a GaInP mixed crystal for this purpose. A GaInP mixed crystal can achieve lattice matching to the GaAs substrate and has a large bandgap as compared with a GaAs compound

10   semiconductor (refractive index is smaller as compared with a GaAs compound semiconductors). Thus, this can be used for the low refractive index layer in place of the AlGaAs mixed crystal. Further, the GaInP mixed crystal semiconductor has an etching

15   selectivity with respect to the AlGaAs mixed crystal semiconductor layer in a wet etching process, and it can be used for the etching stopper layer in the case of forming mesa by a wet etching process. Thereby, the controllability of the wet etching process is

20   improved at the time of forming a surface-emission laser by using such a process.

[Thirty-seventh Embodiment]

A thirty-seventh embodiment of the present

25   invention is a surface-emission laser array formed of

the surface-emission laser diode of the thirty-sixth embodiment.

Figure 150 is a diagram showing an example of the surface-emission laser array of the thirty-
5   seventh embodiment. The surface-emission laser array of Figure 150 is a monolithic laser array in which the surface-emission laser diode of the thirty-sixth embodiment is integrated two-dimensionally in a 3×3 array. In order to drive the surface-emission laser
10 elements independently, there are provided p electrode wirings individually in the surface-emission laser array of Figure 150. It should be noted that the surface-emission laser array of Figure 150 is produced with a procedure and method similar
15 to those of the thirty-sixth embodiment.

In the surface-emission laser array of Figure 150, the individual surface-emission laser elements constituting the surface-emission laser array have the feature of low optical absorption loss
20 and low resistance. In view of the fact that the electric power transformation efficiency is improved further when the laser diode elements are integrated in the form of array, the high surface-emission laser array can provide further improved efficiency.

25 Thus, in the surface-emission laser diode

of the present invention, the slope efficiency is
increased, the oscillation threshold current is
reduced and the electric power transformation
efficiency is increased as noted before, and it is

5   possible to provide a low electric power consumption
device. The surface-emission laser array thus formed
of the surface-emission laser diodes of the present
invention shows very high electric power
transformation efficiency as a whole. Thereby, a very

10   high efficiency device is obtained.

Further, it becomes possible to conduct
parallel optical transmission easily by forming a
surface-emission laser array, and it becomes possible
to conduct optical transmission and optical

15   telecommunication of larger capacity. Further, in the
case a surface-emission laser array oscillating in
the 1.3μm band is constructed by using the active
layer material of the surface-emission laser diode of
the present invention described before, it becomes ·

20   possible to conduct high speed parallel transmission
and communication. Further, in the case a laser array
oscillating in the vicinity of the 1.5μm band is
formed, it becomes possible to conduct wavelength
multiplex communication such as WDM, DWDM, and the

25   like, and a surface-emission laser array capable of

conducting high speed, large capacity optical
transmission or optical telecommunication is provided.

[Thirty-eighth Embodiment]

5   A thirty-eighth embodiment of the present
invention is a surface-emission laser module that
uses the surface-emission laser diode of the thirty-
sixth embodiment or the surface-emission laser array
of the thirty-seventh embodiment.

10   Figure 151 is a diagram showing an example
of the surface-emission laser module of the thirty-
eighth embodiment. The surface-emission laser module
of Figure 151 is constructed by mounting a one
dimension monolithic surface-emission laser array, a
15 micro lens array and a fiber array (silica single
mode fiber) on a silicon substrate.

        Here, it should be noted that the surface-
emission laser array of the thirty-seventh embodiment
is provided so as to oppose the optical fibers and
20 the surface-emission laser array is coupled with the
silica single mode fibers mounted in the V-grooves
that formed on the silicon substrate via a micro lens
array. The oscillation wavelength of this surface-
emission laser array is in the 1.3 μm band and it is
25 possible to conduct high speed parallel optical

transmission by using the silica single mode fibers.

Further, it is possible to obtain a surface-emission laser module of low optical absorption loss and low resistance and high electric

5 power transformation efficiency by using the surface-emission laser array of the thirty-seventh embodiment as the optical source of the surface-emission laser module of this thirty-eighth embodiment.

Thus, the surface-emission laser diode of

10 the thirty-sixth embodiment of reduced optical absorption loss or the surface-emission laser array of the thirty-seventh embodiment is used in the surface-emission laser module of the thirty-eighth embodiment, and as a result, it becomes possible to

15 provide a surface-emission laser module of large slope efficiency, small oscillation threshold current, high electric power transformation efficiency and low electric power consumption.

In the case of the semiconductor surface-

20 emission laser module in which a 1.3μm band surface-emission laser that uses the GaInNAs mixed crystal for the active layer material is combined quartz single mode fibers, in particular, the 1.3μm band coincides with the zero dispersion region of quartz,

25 and the construction becomes particularly suited for

the high speed modulation. Thereby, it becomes possible to conduct high speed and large capacity optical telecommunication and optical transmission by using the surface-emission laser module.

5   Further, in the case of the surface-emission laser module that uses the surface-emission laser diode that oscillates in the 1.5μm band, it becomes possible to conduct the wavelength multiplex communication such as WDM, DWDM, and the like, and

10   high speed and large capacity optical transmission and optical telecommunication becomes possible. As noted above, it becomes possible to provide a surface-emission laser module of excellent characteristics and enabling high speed, large

15   capacity optical transmission and optical telecommunication.

[Thirty-ninth embodiment]

          A thirty-ninth embodiment of the present

20   invention is an optical interconnection system formed of the surface-emission laser diode of the thirty-sixth embodiment, or the surface-emission laser array of the thirty-seventh embodiment, or the surface-emission laser module of the thirty-eighth embodiment.

25   Figure 152 is a diagram showing a parallel

optical interconnection system as an example of the thirty-fortieth embodiment. In the optical interconnection system of Figure 152, it should be noted that a devices 1 and a devices 2 are connected

5   by using an optical fiber array (quartz single mode fiber array). Here, the device 1 at the transmission side includes a surface-emission laser module formed of the surface-emission laser array of the thirty-thirty-ninth embodiment and a driver circuit thereof.

10 Further, the device 2 at the reception side includes a photodiode array module and a signal detection circuit.

In the optical interconnection system of Figure 152, it is possible to reduce the optical

15 absorption loss and the resistance and increase the electric power transformation efficiency by using the surface-emission laser module of the thirty-eighth embodiment, and it is possible to obtain an optical transmission system of excellent characteristics in

20 terms of electric power consumption. Further, by using the surface-emission laser module that used the surface-emission laser array of the present invention in which GaInNAs is used as the active layer, it is possible to construct a stable and highly reliable

25 inter connection system with regard to the change of

environmental temperature.

While the foregoing description was for the example of the parallel optical interconnection system, it is also possible to construct a serial transmission system that uses a single element like the thirty-second embodiment. Further, it is also possible to use the surface-emission laser diode of the thirty-sixth embodiment or the surface-emission laser array of the thirty-seventh embodiment, in addition to the surface-emission laser module of the thirty-ninth embodiment for the optical interconnection system. Further, the present invention can also be applied to the optical interconnection system between devices, optical interconnection between boards, between chips, and inside a chip.

Thus, the thirty-ninth embodiment of the present invention is an optical interconnection system formed by the surface-emission laser diode of the thirty-second embodiment, or the surface-emission laser array of the thirty-seventh embodiment, or the surface-emission laser module of the thirty-eighth embodiment. Because of the use of the surface-emission laser diode or the surface-emission laser array or the surface-emission laser module of low

resistance and low optical absorption loss, this optical interconnection system thus constructed has the feature of high electric power transformation efficiency and low electric power consumption.

5   Particularly, the optical interconnection system formed of the surface-emission laser module, in which the 1.3 μm band surface-emission laser that uses a GaInNAs mixed crystal semiconductor for the active layer material is combined with the quartz

10 single mode fiber, is well suited to the high speed modulation because of the fact that the 1.3 μm band coincides with the zero dispersion band of quartz, and it becomes possible to conduct high speed and large capacity optical transmission. Further, the

15 surface-emission laser diode that uses the GaInNAs mixed crystal semiconductor for the active layer can provide highly stable optical interconnection system of very high reliability in view of the fact that it is possible to obtain the laser oscillation stably up

20 to high temperatures even when there is caused a change of environmental temperature.

Thus, according to the thirty-ninth embodiment of the present invention, it is possible to provide a highly reliable optical interconnection

25 system capable of performing high speed and large

capacity optical transmission and providing high electric power transformation efficiency, by using the surface-emission laser diode of the thirty-sixth embodiment or the surface-emission laser array of the

5   thirty-seventh embodiment or the surface-emission laser module of the thirty-eighth embodiment.

[Fortieth embodiment]

A fortieth embodiment of the present

10   invention is an optical telecommunication system formed of the surface-emission laser diode of the thirty-first embodiment or the surface-emission laser array of the thirty-seventh embodiment or the surface-emission laser module of the thirty-eighth

15   embodiment.

Figure 153 is a diagram showing an optical LAN system as an example of the optical telecommunication system of the fortieth embodiment. The optical LAN system of Figure 153 is formed of the

20   surface-emission laser diode of the thirty-sixth embodiment or the surface-emission laser array of the thirty-seventh embodiment or the surface-emission laser module of the thirty-eighth embodiment.

Thus, in the light LAN system of Figure 153,

25   the surface-emission laser diode of the thirty-sixth

embodiment, the surface-emission laser array of the thirty-seventh embodiment, or the surface-emission laser module of the thirty-eighth embodiment, is used for the optical source of the optical transmission

5   between the server and the core switch and/or between the core switch and the switches and/or between the switch and each terminal. Thereby, the connection between the devices is achieved by using a quartz single mode fiber or a multiple mode fiber. An

10 example of the physical layer of such an optical LAN may be Giga-bit Ethernet of 1000BASE-LX.

In the optical LAN system of Figure 153, it becomes possible to reduce the optical absorption loss of the oscillation light and decrease the device

15 resistance while increasing the electric power transformation efficiency as a result of use of the surface-emission laser diode of the thirty-sixth embodiment or the surface-emission laser array of the thirty-seventh embodiment or the surface-emission

20 laser module of the thirty-eighth embodiment for the optical source of the optical transmission, and it becomes possible to provide an optical transmission system of small electric power consumption. In the surface-emission laser of the present invention that

25 uses GaInNAs for the active layer, in particular, it

is possible to achieve stable oscillation even if there is caused change of the environment temperature, drive condition, and the like, and it is possible to construct a highly reliable optical telecommunication

5   system.

Thus, the fortieth embodiment of the present invention is the optical telecommunication system formed of the surface-emission laser diode of the thirty-sixth embodiment, or the surface-emission

10   laser array of the thirty-seventh embodiment, or the surface-emission laser module of the thirty-eighth embodiment. Because the use of the low resistance surface-emission laser diode or surface-emission laser array or the surface-emission laser module

15   wherein the optical absorption loss is reduced, it becomes possible to construct an optical telecommunication system having high electric power transformation efficiency and low electric power consumption.

20   Particularly, the optical telecommunication system that uses the surface-emission laser module in which the 1.3 μ m band surface-emission laser having an active layer of the GaInNAs mixed crystal semiconductor is combined with a quartz single mode

25   fiber is suited for high speed modulation , because

of the fact that the 1.3 μm band coincides to the
zero dispersion band of quartz. Thereby, it becomes
possible to conduct high-speed and large capacity
optical telecommunication and optical transmission.

5   Also, the surface-emission laser diode having the
active layer of GaInNAs mixed crystal semiconductor
can achieve stable oscillation up to high
temperatures even if there is caused change of the
environment temperatures, and the like, and, it

10   becomes possible to obtain highly reliable optical
telecommunication system.

Thus, by using the surface-emission laser
diode of the thirty-sixth embodiment or the surface-
emission laser array of the thirty-seventh embodiment

15   or the surface-emission laser module of the thirty-
eighth embodiment in the fortieth embodiment, it
becomes possible to conduct high speed and large
capacity optical telecommunication, and it becomes
possible to provide a highly reliable optical

20   telecommunication system having high the electric
power transformation efficiency and capable of
conducting high-speed and large capacity optical
communication.

Although the foregoing explanation was made

25   for the case of using LAN as the optical

telecommunication system, the present invention can
be applied also to the other systems such as trunk
line system, WAN, MAN, and the like. Further, the
terminal can be used in all the information device

5   terminals that conduct transfer of information by way
of light.

[Forty-first Embodiment]

In a forty-first embodiment, the present
10   invention provides an n-type semiconductor
distributed Bragg reflector in which first and second
semiconductor layers of different refractive indices
(bandgap) are stacked, wherein there is provided an
intermediate layer (semiconductor layer) between the
15   first and second semiconductor layers with a
refractive index intermediate of the first and second
semiconductor layers.

In this forty-first embodiment, depletion
of carriers at the heterointerface of the n-type
20   semiconductor distributed Bragg reflector is
suppressed by way of providing the intermediate layer
(semiconductor layer) having an intermediate
refractive index (bandgap) of the refractive indices
of the first and second semiconductor layers, and the
25   electrostatic capacitance of the n-type semiconductor

distributed Bragg reflector is successfully reduced.

In a semiconductor heterointerface of a semiconductor distributed Bragg reflector formed by semiconductor layers of different refractive indices

5   (bandgap), there is caused a potential distribution called spike or notch at the heterointerface as a result of the difference of doping density and electron affinity between the semiconductors. In the part formed with spike, for example, there is formed

10   a high potential barrier for the carriers, and depletion of the carriers is caused as a result of this. In the part where a notch is formed, on the other hand, there is caused accumulation of carriers because of the decrease of the potential barrier.

15   Thus, the distribution of carriers in the heterointerface is not uniform, and the device characteristic is influenced heavily by the existence of the heterointerface.

It is known in the case of a p-type

20   semiconductor distributed Bragg reflector that the device resistance increases significantly due to the influence of the spike at the heterointerface in view of the fact that the holes constituting the majority carrier (hole) have a large effective mass. In the

25   case of an n-type semiconductor distributed Bragg

reflector, the influence of the heterointerface on the device resistance is thought as being smaller, in view of the fact that the effective mass of the electrons constituting the majority carrier is

5 smaller as compared with holes. However, no detailed examination has been made conventionally about the influence of the heterointerface for the case of an n-type semiconductor distributed Bragg reflector. However, the phenomenon of depletion of carriers is

10 caused irrespective of the conductivity type in the heterointerface as noted above, and electrostatic capacitance is caused inevitably as a result of the carrier depletion.

Hereinafter, explanation will be made about

15 the current-voltage characteristic of Figure 167 based on the assumption that the heterointerface provides the influence to the device characteristic. It should be noted that the current-voltage characteristic of Figure 167 compares the measurement

20 result conducted on the n-type semiconductor distributed Bragg reflector formed of AlAs/GaAs shown Figure 146 for the case of pulse measurement and for the case of CW (continuation wave) measurement. As for the device of Figure 168, it should be noted that

25 the device is an n-type semiconductor distributed

Bragg reflectors formed on an n-GaAs substrate by

forming 35 stacks of AlAs/GaAs unit structure by

conducting a crystal growth process. In the device of

Figure 168, ohmic electrodes are provided to the rear

5   surface of the n-GaAs substrate and further to the

removal part (stripe-formed oxide removal part having

a width of $40\mu m$ and a length of $500\mu m$) formed in

the SiO$_2$ insulation layer on the n-type semiconductor

distributed Bragg reflector layer. In the n-type

10   semiconductor distributed Bragg reflector of Figure

168, it should be noted that the intermediate layer

(compositional graded layer) is not provided to the

interface of the AlAs/GaAs structure, and thus, the

composition changes steeply at each interface. In

15   Figure 167, it can be seen that there exists a large

difference in the current-voltage characteristic

between the CW measurement and the pulse measurement.

In the pulse measurement, in particular, it can be

seen that the application voltage is high and the

20   device resistance is large. Further, in the case of

the CW measurement, too, it can be seen that negative

resistance appears in the vicinity of the current

value of 500mA. From this, it can be seen the

situation in which the depletion or accumulation of

25   carriers at the heterointerface exerting influence on

the device characteristics. Thus, there is caused

non-linearity (negative resistance) in the current-

voltage characteristic for the n-type distributed

Bragg reflector having a steep heterointerface,

5   wherein the cause of this non-linearity is attributed

to tunneling of carriers, and the like, at the hetero

barrier. Further, there is caused change of current-

voltage characteristic due to the difference of the

measurement condition of the device.

10   Figure 169, on the other hand, is a diagram

showing the current-voltage characteristic of the

device having a structure similar to that Figure 146

for the case there is provided a linear compositional

graded layer at each interface of the AlAs/GaAs

15   structure constituting the n-type semiconductor

distributed Bragg reflector as an intermediate layer.

In Figure 169, the cases in which the thickness of

the linear shape compositional graded layer is set to

20nm and 30nm are shown. In Figure 169, it should be

20   noted that the difference between the pulse

measurement and the CW measurement is reduced as

compared with the case of Figure 167, and the

linearity of the characteristics is improved. Thus,

the difference of the current-voltage characteristic

25   between the measurement conditions (drive condition)

is improved substantially, and the non-linearity

(negative resistance) observed at the time of the CW

measurement is also improved substantially. Thus, the

influence of the heterointerface on the current-

5   voltage characteristics is reduced substantially, and

along with this, the electrostatic capacitance caused

by the depletion at the interface is reduced

substantially.

In a surface-emission laser diode, the

10   device resistance and the electrostatic capacitance

determine the upper limit of modulation speed of the

device by way of miniaturization of the device size

and oxidation confinement diameter. Accordingly, it

is very important to reduce the device resistance and

15   capacitance as small as possible in order to realize

high speed modulation exceeding 10Gbps. Thus, it is

important to reduce the capacitance at the interface

of the semiconductor distributed Bragg reflector in

addition to providing the oxidation confinement layer.

20   Further, the observed change of the current-voltage

characteristic changes with the measurement condition

as shown in Figure 167 and the non-linearity in the

current-voltage characteristic are not desirable in

view point of practical use of the device.

25   In the case of providing an intermediate

layer (semiconductor layer (a linear compositional graded layer in the present case)) having a refractive index (bandgap) intermediate of the semiconductor layers constituting an n-type

5   semiconductor distributed Bragg reflector as in the case of the forty-first embodiment, it is possible to suppress the occurrence of the potential distribution such as spike, notch, and the like, as it shown in Figure 169. By smoothing the potential barrier at the

10 heterointerface like this, it becomes possible to drastically reduce the accumulation or depletion of carriers taking place at the heterointerface conventionally. With this, the electrical resistance is also reduced. Further, by reducing the influence

15 of the heterointerface effectively, it is also possible to reduce the non-linearity of the current-voltage characteristic of a n-type distributed Bragg reflector and the change of the current-voltage characteristic by drive condition. Further, as a

20 result of suppressing of the depletion of carriers at the heterointerface, the electrostatic capacitance by the depletion region is reduced substantially. Like this, it becomes possible to improve the current-voltage characteristic of the n-type semiconductor

25 distributed Bragg reflector. Further, as a result of

decrease of the electrostatic capacitance, driving is
easily made in a surface-emission laser diode that
uses an n-type semiconductor distributed Bragg
reflector for the reflector as compared with a
5 conventional device, and further high-speed
modulation becomes possible.

Thus, in the forty-first embodiment, there
is provided an intermediate layer (semiconductor
layer) between first and second semiconductor layers
10 having respective, mutually different refractive
indices and constituting an n-type semiconductor
distributed Bragg reflector, such that the
intermediate layer has a refractive index
intermediate of the first and second semiconductor
15 layers so as to decrease low the influence of the
electrostatic capacitance of the n-type semiconductor
distributed Bragg reflector. By smoothing the
potential barrier at the heterointerface, it becomes
possible to reduce the change of the current-voltage
20 characteristic caused by the difference of drive
(measurement) condition and the non-linearity of the
current-voltage characteristics. Further, the
electrostatic capacitance caused by the depletion of
carriers is also reduced. From above, the present
25 embodiment can provide an n-type distributed Bragg

reflector having a reduced electrostatic capacitance at the semiconductor heterointerface.

[Forty-second Embodiment]

5   A forty-second embodiment of the present invention has a construction in which the thickness of the above-mentioned intermediate layer is set larger than 20 [nm] in the distributed Bragg reflector of the forty-first embodiment.

10   In the forty-second embodiment, it becomes possible to obtain an n-type distributed Bragg reflector having excellent electric characteristics such as reduced non-linearity in the current-voltage characteristics, reduced change of current-voltage

15   characteristics by measurement condition and reduced electrostatic capacitance at the heterointerface, by setting the thickness of the intermediate layer to the foregoing thickness and by smoothing the potential barrier at the heterointerface.

20   Referring to Figure 169 again, it can be seen that the difference between the CW measurement and the pulse measurement is reduced substantially in the structure of Figure 169 in which there is provided the compositional graded layer (intermediate

25   layer) with the thickness of 20nm, as compared with

the structure of Figure 167 in which the intermediate
layer is not provided. By providing the intermediate
layer to each of the interfaces of the n-type
distributed Bragg reflector with the thickness of

5   20nm or more, these problems are reduced
significantly. Thus, the difference of the current-
voltage characteristic between the pulse measurement
and the CW measurement is reduced substantially by
providing the compositional graded layer with the

10   thickness of 20nm. Further, it can be seen that the
non-linearity of the current-voltage characteristic
seen in the CW measurement is eliminated. These
results show that the potential barrier at the
heterointerface of the Bragg reflector can be

15   smoothed substantially by providing the compositional
graded layer of the thickness of 20nm. Along with
this, the electrostatic capacitance caused by
depletion of the carriers at the heterointerface can
be reduced substantially.

20   In the forty-second embodiment, the
influence of the heterointerface is reduced
substantially and the current-voltage characteristic
of the n-type distributed Bragg reflector is improved
substantially by providing a compositional graded

25   layer with a thickness larger than 20nm, and the

electrostatic capacitance at the heterointerface is reduced.

[Forty-third Embodiment]

A forty-third embodiment of the present invention has a construction in which the thickness of the above-mentioned intermediate layer set to 30nm or more in the n-type distributed Bragg reflector of the forty-first embodiment.

In the forty-third embodiment, it is possible to obtain an n-type distributed Bragg reflector of excellent electric characteristics in which the influence of the heterointerface is more effectively reduced and the electrostatic capacitance at the heterointerface is more effectively reduced, by setting the thickness of the intermediate layer to the above thickness.

The reason that the influence of the heterointerface is reduced is that the heterointerface is smoothed by the intermediate layer and the accumulation or depletion of the carriers at the interface is suppressed. This function is enhanced with increasing thickness of the intermediate layer. Here, reference is made again to the current-voltage characteristic of Figure 169. In

Figure 169, it can be seen that the differences of current-voltage characteristics between the pulse measurement and the CW measurement is reduced and the non-linearity at the time of the CW measurement are

5 reduced as a result of the effect of smoothing of the potential barrier at the heterointerface caused by the intermediate layer, for both of the specimens in which the thickness of the compositional graded layer (intermediate layer) is changed. Especially, it can

10 be seen that the aforementioned point is improved more in the specimen in which the compositional graded layer having the thickness of 30nm is provided. In this case, the difference between the CW measurement and the pulse measurement is almost

15 vanished. Therefore, it is possible to enhance the improving effect by setting the thickness of the intermediate layer to be 30nm or more.

In the forty-third embodiment, the influence of the heterointerface is reduced more

20 effectively as noted before by providing the compositional graded layer of the thickness of 30nm or more. Thus, the current-voltage characteristic of the n-type distributed Bragg reflector is improved more effectively and the electrostatic capacitance at

25 the heterointerface is reduced effectively. As noted

above, it is possible to reduce the change of the
current-voltage characteristics and non-linearity of
the current-voltage characteristics effectively in
the present embodiment, and the electrostatic
5   capacitance at the heterointerface can be reduced
more effectively. From above, an n-type distributed
Bragg reflector having excellent electric
characteristics is obtained.

10   [Forty-fourth Embodiment]

        A forty-fourth embodiment of the present
invention has a construction in which the thickness t
[nm] of the above-mentioned intermediate layer is set
with respect to the reflection wavelength λ [um] of
15   the distributed Bragg reflector to fall in the range
of $20 < t \leqq (50\lambda - 15)$ [nm] in the n-type distributed
Bragg reflector of the forty-first embodiment.

        When the thickness of the intermediate
layer is excessive, the reflectivity of the
20   distributed Bragg reflector falls off rapidly. On the
other hand, the effect of planarizing the
heterointerface is enhanced when the thickness of the
intermediate layer is increased. Thus, there exists
an optimum range for the intermediate layer thickness
25   that satisfy both of these requirements. In the

present embodiment, an n-type distributed Bragg

reflector having excellent electric characteristics

is obtained by reducing the effect of the

heterointerface while simultaneously maintaining the

5   high reflectivity by choosing the thickness of the

intermediate layer with respect to the reflection

wavelength λ [μm] of the distributed Bragg reflector

so as to fall in the range of $20 < t \leqq (50\lambda - 15)$ [nm].

In the forty-fourth embodiment, it becomes

10 possible to obtain an n-type distributed Bragg

reflector of excellent electrical characteristics in

which the influence of the heterointerface is reduced

while maintaining high reflectivity, by making use of

the aforementioned construction. Larger the

15 refractive-index difference between the semiconductor

layers constituting the distributed Bragg reflector,

and steeper the interface, the reflectivity of the

distributed Bragg reflector increases. Thus, with

increasing thickness of the compositional graded

20 layer, the reflectivity tends to decrease gradually.

Figure 170 shows this situation. Thus,

Figure 170 is a diagram showing the differential

coefficient of the reflectivity change to the

thickness of the compositional graded layer for the

25 case of the distributed Bragg reflector formed of

AlAs/GaAs for each wavelength band. It should be

noted that the stacking number of the distributed

Bragg reflector is set such that the reflectivity has

just exceeded 99.9% in each of the wavelength bands.

5 From Figure 170, it can be seen that the reflectivity

starts to change (decline) gradually at first while

the reflectivity changes sharply from a certain value.

In order to facilitate understanding of this

situation, tangent lines are drawn to the thickness

10 in which the differential coefficient starts to

change in Figure 170 at several wavelength bands.

From these tangent lines, it can be seen that the

differential coefficient starts to change sharply in

the vicinity where differential coefficient becomes

15 0.01 in any of the wavelength bands. Thus, the

thickness corresponding to the differential

coefficient of 0.01 is the thickness in which the

reflectivity of the distributed Bragg reflector

starts to increase sharply (threshold thickness).

20 When the thickness of the compositional graded layer

is set larger than this threshold thickness, the

reflectivity of the distributed Bragg reflector falls

off sharply. The thickness of the compositional

graded layer (threshold thickness) providing the

25 differential coefficient of 0.01 can be read from the

next table (Table 13) for the respective wavelength bands as follows. There exists a linear relationship as follows (equation 1) between the reflection wavelength λ [um] of the Bragg reflector and the

5   threshold thickness.

TABLE 13

Reflection wavelength	$1.1\,\mu m$	$1.3\,\mu m$	$1.3\,\mu m$	$1.7\,\mu m$
Threshold thickness	40nm	50nm	60nm	70nm

Threshold thickness = $(50\lambda - 15)$ [nm]   Eq. (1)

10   Here, the reflection wavelength is the wavelength in which the reflectivity becomes highest in the reflection band of the distributed Bragg reflector. Further, the thickness of the layer constituting the Bragg reflector and having the

15   refractive index n is represented with respect to the reflection wavelength λ as $\lambda/4n$ in the structure in which the intermediate layer is not provided.

As noted above, the effect of improving the difference of the current-voltage characteristics by

20   the drive condition, the non-linearity of the current-voltage characteristics, and the accumulation

or depletion of the carriers at the heterointerface becomes conspicuous in the case the thickness of the intermediate layer is large. From this viewpoint, it is desirable to provide a thick intermediate layer.

5 However, there arise problems as noted above in the case that the thickness of the intermediate layer is too large. Thus, there is an optimal range for the thickness of the intermediate layer.

From the aforementioned result, the optimum

10 thickness range of the intermediate layer can be represented with respect to the reflection wavelength λ [μm] of the distributed Bragg reflector as $20 < t \leq$ $(50\lambda - 15)$ [nm], in view of the electric characteristics (current-voltage characteristics) and

15 in view of the optical characteristics (reflectivity). Here, the inequality that determines the range of the intermediate layer thickness t holds within the range of $\lambda > 0.7\mu$m, and can be applied to the n-type distributed Bragg reflector having the reflection

20 wavelength longer than this wavelength. For example, the device that uses the AlGaAs system material to the active layer can obtain laser oscillation in typically in the 0.78μm $- 0.85$ μm band. In the case a GaInAs system is used, it is possible obtain the

25 laser oscillation in the 0.98μm band to 1.2μm band.

In the case of using the GaInNAsSbP material system, it is possible to obtain laser oscillation in the wavelength region longer than the $1.2\,\mu$m band.

Thus, the n-type distributed Bragg

5   reflector having the intermediate layer with the thickness falling in the range determined by the forty-fourth embodiment can be used for a laser based on such a material and having the wavelength longer than $0.7\,\mu$m or a device such as optical modulator.

10

[Forty-fifth Embodiment]

A forty-fifth embodiment of the present invention provides a surface-emission laser diode that uses the n-type semiconductor distributed Bragg

15   reflectors of any of forty-first through forty-fourth embodiments.

· In the surface-emission laser diode of the forty-fifth embodiment, the electrostatic capacitance of the surface-emission laser diode is reduced and

20   high speed modulation becomes possible as a result of use of the n-type semiconductor distributed Bragg reflectors of any of the forty-first through forty-fourth embodiments.

Thus, in the surface-emission laser diode

25   of the forty-fifth embodiment, the potential

distribution such as spike or notch formed at the interface of the n-type semiconductor distributed Bragg reflector is smoothed by using the n-type semiconductor distributed Bragg reflectors of any of

5 the forty-first forty-through forty-fourth embodiments. Thus, the influence of depletion or accumulation of carriers caused by the spike or notch is successfully reduced as compared with a conventional surface-emission laser diode, and

10 surface-emission laser diode of the forty-fifth embodiment provides reduced electrical resistance as well as reduced electrostatic capacitance at the heterointerface.

Thus, the surface-emission laser diode of

15 the forty-fifth embodiment has a structure suitable for high speed modulation as compared with a conventional surface-emission laser diode. As a result of decrease of the electrostatic capacitance of the n-type semiconductor distributed Bragg

20 reflector, it can easily perform high speed modulation exceeds 10Gbps.

[Forty-sixth Embodiment]

A forty-sixth embodiment of the present

25 invention provides a surface-emission laser diode in

which an n-type semiconductor distributed Bragg
reflector and a p-type semiconductor distributed
Bragg reflector are provided across an active layer,
wherein the n-type semiconductor distributed Bragg

5   reflector is processed to form a mesa.

Thus, in this forty-sixth embodiment, the
n-type semiconductor distributed Bragg reflector is
processed to form a mesa in the surface-emission
laser diode in which the n-type semiconductor

10   distributed Bragg reflector and the p-type
semiconductor distributed Bragg reflector are
provided across the active layer, and as a result,
the path of the current injected to the device part
(cavity region) of the laser diode through the n-type

15   semiconductor distributed Bragg reflector is limited.
As a result, the area of the n-type semiconductor
distributed Bragg reflector contributing to the
electrostatic capacitance is decreased, and the
electrostatic capacitance is reduced, and as a result,

20   high speed modulation becomes possible.

Thus, in the forty-sixth embodiment, the n-
type semiconductor distributed Bragg reflector is
processed to form a mesa in the surface-emission
laser diode in which the n-type semiconductor

25   distributed Bragg reflector and the p-type

semiconductor distributed Bragg reflector are
provided across the active layer (More specifically,
the n-type semiconductor distributed Bragg reflector
is removed by an etching process except for the
5   region forming the device part (cavity region) such
that the etching reaches the substrate surface as
will be explained later with reference to Figure 157).
As explained before, there is formed a potential
distribution of spike or notch at the heterointerface
10   formed two semiconductor layers of different electron
affinity, and there is formed electrostatic
capacitance as a result of depletion of carriers.
Further, it has been practiced in a conventional
surface-emission laser element to provide an
15   oxidation confinement structure for reducing the
threshold current by oxidizing the semiconductor
layer that contains Al such as AlAs, and the like.
Because holes have a shorter diffusion length as
compared with electrons and thus higher confinement
20   efficiency is obtained with holes as compared with
electrons, the foregoing confinement structure is
usually provided in the p-type semiconductor
distributed Bragg reflector. Generally, no
confinement structure is provided in the n-type
25   semiconductor distributed Bragg reflector, and

injection of electrons is conducted as the majority

carrier from the electrode formed on the entire rear

surface of the substitute substrate. Thus,

conventional surface-emission laser diode generally

5   has a wider current path for the electrons as

compared with the mesa diameter that constitutes the

path of the holes, and the area for the electron

current in the n-type semiconductor distributed Bragg

reflector pass is larger than the p-type

10 semiconductor distributed Bragg reflector. As

electrostatic capacitance increases in proportion to

the area, the electrostatic capacitance of the n-type

semiconductor distributed Bragg reflector increases

in correspondence to the spreading of the current.

15 This has been the cause of increase of the device

capacity.

In this forty-sixth embodiment, the current

path of the electrons is confined by removing the n-

type semiconductor distributed Bragg reflector by way

20 of an etching process except for a region

corresponding to the device part (cavity region) to

the region left at the time of the foregoing etching

removal process. With this, it becomes possible to

reduce the electrostatic capacitance caused by the n-

25 type semiconductor distributed Bragg reflector. Thus,

the surface-emission laser diode of the forty-sixth
embodiment is a structure suitable for high speed
modulation as compared with conventional surface-
emission laser diodes. In the surface-emission laser
5   diode of the forty-sixth embodiment, it becomes
possible to perform high speed modulation of 10Gbps
or more easily as a result of reduction of the
electrostatic capacitance of the n-type semiconductor
distributed Bragg reflector.

10   By confining the current path in the n-type
semiconductor distributed Bragg reflector to the
degree comparable with the mesa diameter of the
device part (cavity region) in the surface-emission
laser diode in the forty-sixth embodiment, the area
15   of the n-type semiconductor distributed Bragg
reflector that contributes to the electrostatic
capacitance is reduced and the electrostatic
capacitance of the device is reduced. Thereby, high
speed modulation becomes possible.

20

[Forty-seventh Embodiment]

A forty-seventh embodiment of the present
invention provides a surface-emission laser diode in
which an n-type semiconductor distributed Bragg
25   reflector and a p-type semiconductor distributed

Bragg reflector are provided across an active layer
wherein the region other than the cavity region of
the n-type semiconductor distributed Bragg reflector
is formed to have a high resistance.

5   In the surface-emission laser diode of the
forty-seventh embodiment in which the n-type
semiconductor distributed Bragg reflector and the p-
type semiconductor distributed Bragg reflector are
provided across the active layer, the resistance of
10   the n-type semiconductor distributed Bragg reflector
is increased in the region other than the cavity
region, and the path of the current injected to the
device region (cavity region) through the n-type
semiconductor distributed Bragg reflector is confined.
15   Thereby, the area of the n-type semiconductor
distributed Bragg reflector, which contributes to the
electrostatic capacitance, is decreased, and the
electrostatic capacitance is effectively reduced.
Thus, high speed modulation becomes possible.

20   Thus, in the forty-seventh embodiment, the
resistance of the n-type semiconductor distributed
Bragg reflector is increased except for the region of
the device part (cavity region). As a result of
confinement of the current path of the electrons
25   injected from the substrate side to only a part of

the mesa region of the n-type semiconductor
distributed Bragg reflector, the area of the n-type
semiconductor distributed Bragg reflector
contributing to the electrostatic capacitance is

5   reduced similarly to the case of the forty-sixth
embodiment. Thus, it becomes possible to reduce the
electrostatic capacitance of the surface-emission
laser diode as compared with the case of a
conventional surface-emission laser diode, and a

10 structure suitable for the high speed modulation is
obtained.

In other words, the area of the n-type
semiconductor distributed Bragg reflector
contributing to the electrostatic capacitance is

15 reduced by confining the current path in the n-type
semiconductor distributed Bragg reflector to the mesa
diameter of the device part (cavity region) as in the
case of the forty-sixth embodiment also in the
surface-emission laser diode of the forty-seventh

20 embodiment, and electrostatic capacitance of the
device is effectively reduced. Thereby, high speed
modulation becomes possible.

For the method of increasing the resistance
of an n-type semiconductor distributed Bragg

25 reflector, it is possible to use hydrogen ion

implantation, and the like, as will be described
later with reference to forty-fifth embodiment. In
view of the fact that the distance between the active
region and the etching surface is small, it is easy
5   to achieve various advantages such as excellent heat
radiation, easiness of burying, excellent physics
strength, and the like, as a result of use of the
hydrogen ion implantation process. Particularly, the
feature of excellent heat radiation enables high
10   output operation of the laser diode. In fact, it
becomes possible to perform high speed modulation of
10Gbps or more easily in the surface-emission laser
diode of the forty-seventh embodiment by reducing the
electrostatic capacitance of the n-type semiconductor
15   distributed Bragg reflector.

[Forty-eighth Embodiment]
         A forty-eighth embodiment of the present
invention provides a surface-emission laser diode of
20   the forty-sixth or forty-seventh embodiment having
the above-mentioned n-type semiconductor distributed
Bragg reflector in which first and second
semiconductor layers of different refractive indices
are stacked, wherein there is provided an
25   intermediate layer (semiconductor layer) having a

refractive index intermediate of the refractive
indices of the first and second semiconductor layers.

In the forty-eighth embodiment, there is
provided an intermediate layer (semiconductor layer)
5   in the surface-emission laser diode of the forty-
sixth or forty-seventh embodiment in the n-type
semiconductor distributed Bragg reflector between the
first and second semiconductor layers having
respective, mutually different refractive indices,
10 with a refractive index intermediate of the foregoing
first and second semiconductor layers. With this, the
electrostatic capacitance of the heterointerface in
the n-type semiconductor distributed Bragg reflector
can be reduced significantly. Thereby, further high
15 speed modulation becomes possible.

Thus, in the forty-eighth embodiment, there
is provided an intermediate layer (semiconductor
layer) to the heterointerface formed by the first and
second semiconductor layers constituting the n-type
20 semiconductor distributed Bragg reflector in the
surface-emission laser diode of the forty-sixth or
forty-seventh embodiment with a refractive index
(bandgap) intermediate of the two semiconductor
layers, and because of this, the potential at the
25 heterointerface is smoothed as a result of providing

the intermediate layer (semiconductor layer) to the heterointerfaces of the first and second semiconductor layers as explained in any of forty-first through forty-fifth embodiments, and depletion

5 or accumulation of carriers is reduced. With this, the electrostatic capacitance caused by the depletion is reduced significantly. By confining the path of the electrons of the n-type semiconductor distributed Bragg reflector to the mesa region similarly to the

10 forty-sixth or forty-seventh embodiment. Thus, by combining these as in the case of the forty-eighth embodiment, the area of the semiconductor distributed Bragg reflector that contributes effectively to the capacitance is reduced, the electrostatic capacitance

15 of the surface-emission laser diode is reduced further, and it becomes possible to obtain the structure very suitable for high speed modulation. In fact, the surface-emission laser diode of the forty-eighth embodiment can perform high speed modulation

20 of 10Gbps or more easily as a result of decrease of the electrostatic capacitance of the n-type semiconductor distributed Bragg reflector as noted above.

25 [Forty-ninth Embodiment]

A forty-ninth embodiment of the present invention, provides a surface-emission laser diode of the forty-sixth or forty-seventh embodiment in which the n-type semiconductor distributed Bragg reflector

5   includes an intermediate layer between the first and second semiconductor layers having respective, mutually different refractive indices with a refractive index intermediate of the first and second semiconductor layers and wherein the thickness of the

10   above-mentioned intermediate layer is set to be larger than 20 [nm].

By using the construction of the forty-ninth embodiment, it becomes possible to reduce the area of the n-type semiconductor distributed Bragg

15   reflector contributing to the electrostatic capacitance by confining the path of the electrons current, and the electrostatic capacitance of the heterointerface of the n-type semiconductor distributed Bragg reflector is reduced. Thereby, high

20   speed modulation becomes possible.

Thus, by providing the semiconductor layer explained before to the heterointerface as explained with reference to forty-first or forty-second embodiment, the depletion or accumulation of the

25   carriers is reduced as a result of smoothing of the

potential distribution at the heterointerface as
compared with the case in which such an interface
layer is not provided, and the electrostatic
capacitance caused by the depletion is reduced
5   significantly. Further, by confining the path of the
electrons by etching of the n-type semiconductor
distributed Bragg reflector or increase of resistance
as set forth in forty sixth or forty seventh
embodiment, the area of the semiconductor distributed
10 Bragg reflector contributing to the capacitance can
be reduced. Thus, by combining these features as set
forth in the present embodiment, it is possible to
reduce the electrostatic capacitance of the device
further, and a structure extremely suitable for high
15 speed modulation is obtained. The device of the
present embodiment can perform the high speed
modulation of 10GPs or more as a result of decrease
of the electrostatic capacitance of the n-type
distributed Bragg reflector.
20

[Fiftieth Embodiment]

    A fiftieth embodiment of the present
invention has a construction in which the n-type
semiconductor distributed Bragg reflector of the
25 surface-emission laser diode of the forty-sixth or

forty-seventh embodiment includes an intermediate layer between the first and second semiconductor layers having respective, mutually different refractive indices with a refractive index

5   intermediate of the first and second semiconductor layers, wherein the thickness of the intermediate layer is set to be 30 [nm] or more.

By using the construction of the fiftieth embodiment, it becomes possible to reduce the area of

10   the n-type semiconductor distributed Bragg reflector contributing to the electrostatic capacitance by confining the path of the electron current, and it becomes possible to reduce the electrostatic capacitance of the heterointerface of the n-type

15   semiconductor distributed Bragg reflector. Thereby, high speed modulation becomes possible.

Thus, by providing the semiconductor layer explained before to the heterointerface as explained with reference to forty-first or forty-second

20   embodiment, the depletion or accumulation of the carriers is reduced sufficiently as a result of smoothing of the potential distribution at the heterointerface, and the electrostatic capacitance caused by the depletion is reduced furthermore.

25   Further, by confining the path of the electrons by

etching of the n-type semiconductor distributed Bragg reflector or increase of resistance as set forth in forty sixth or forty seventh embodiment, the area of the semiconductor distributed Bragg reflector

5 contributing to the capacitance can be reduced. Thus, by combining these features as set forth in the present embodiment, it is possible to reduce the electrostatic capacitance of the device furthermore effectively, and a structure extremely suitable for

10 high speed modulation is obtained. The device of the present embodiment can perform the high speed modulation of 10GPs or more as a result of decrease of the electrostatic capacitance of the n-type distributed Bragg reflector.

15

[Fifty-first Embodiment]

A fifty-first embodiment of the present invention has a construction in which the n-type semiconductor distributed Bragg reflector forming the

20 surface-emission laser diode of the forty-sixth or forty-seventh embodiment includes an intermediate layer between the first and second semiconductor layers having respective, mutually different refractive index with a refractive intermediate of

25 the first and second semiconductor layers, wherein

the thickness t [nm] of the above-mentioned
intermediate layer is determined in relation to the
reflection wavelength λ [um] of the distributed Bragg
reflector so as to fall in ranges of $20 < t \leqq (50\lambda - 15)$
5   [nm].

By using the construction of the fifty-
first embodiment, it becomes possible to reduce the
area of the n-type semiconductor distributed Bragg
reflector that contributing to the electrostatic
10   capacitance by limiting the path of the electron
current, and the electrostatic capacitance of the
heterointerface of a n-type semiconductor distributed
Bragg reflector is reduced. Thereby, high speed
modulation becomes possible.

15   Thus, the potential distribution at the
heterointerface is smoothed by providing the
semiconductor layer to the heterointerfaces as
explained with reference to the forty-first through
forty-third embodiments, and depletion or
20   accumulation of carriers is reduced. Thereby, the
electrostatic capacitance caused by the depletion is
significantly reduced. Further, by choosing the
thickness of the intermediate layer to the foregoing
range, high reflectivity is maintained for the n-type
25   distributed Bragg reflector. Thus, a surface-emission

laser diode characterized by low threshold current is obtained.

By confining the path of the electrons to the mesa region by etching or increase of resistance of the n-type semiconductor distributed Bragg reflector, the area of the semiconductor distributed Bragg reflector contributing to the capacitance is reduced. Thus, by combining these features as in the present embodiment, it is possible to reduce the electrostatic capacitance further, and a structure extremely suitable for high speed modulation is obtained. The device of the present embodiment can perform the high speed modulation of 10Gbps or more as a result of decrease of the electrostatic capacitance of the n-type semiconductor Bragg reflector.

[Fifty-second Embodiment]

A fifty-second embodiment of the present invention has a construction of the surface-emission laser diode of any the forty-fifth through fifty-first embodiments, wherein the present embodiment has a feature in that the active layer is formed of a group III element and a group V element, the group

III element of the active layer being any or all of Ga and In, the group V element of the active layer being any or all of As, N, Sb and P.

In this fifty-second embodiment, the active

5   layer is formed of the group III element and the group V element in the surface-emission laser diode of any of the forty-fifth through fifty-first embodiments, wherein the group III element of the active layer is any or all of Ga and In, while the

10   group V element of the active layer is any or all of As, N, Sb and P. With this, it becomes possible to obtain a surface-emission laser diode oscillating at wavelength longer than 1.1μm including the 1.3μm band and 1.5μm band, which are important for

15   optical-fiber telecommunication, on a GaAs substrate. Further, because it is possible to use GaAs for the semiconductor substrate, a high quality semiconductor distributed Bragg reflector formed of AlGaAs/GaAs for the cavity reflector. Thereby, it becomes possible to

20   provide a surface-emission laser diode of excellent characteristics and low threshold for the use in long wavelength band application.

Thus, in the fifty-second embodiment, the group III element of the active layer is chosen from

25   any or all of Ga and In and the group V element of

the active layer is chosen from any or all of As, N,
Sb and P, while it should be noted that the active
layer formed of these materials can be grown on a
GaAs substrate by way of crystal growth process. Thus,

5   it is possible to obtain a surface-emission laser
diode having excellent characteristics in terms of
reflectivity, thermal conductivity, process
controllability (crystal growth or selective
oxidation of the Al(Ga)As mixed crystal) by using the

10   AlGaAs system material for the DBR. Further, it is
possible to obtain the oscillation at the wavelength
of $0.85\mu m$ band and 0.98_m band and further at the
wavelength longer than $1.1\mu m$, including the $1.3\mu m$
band and $1.5\mu m$ band which are important for optical-

15   fiber telecommunication, by using these materials for
the active layer.

       Thereby, it becomes possible to conduct
high speed optical telecommunication by combining the
laser device of the $1.3\mu m$ wavelength band with a

20   silica single mode laser. Further, it is possible to
conduct large capacity communication by using DWDM by
the device of the $1.5\mu m$ band.

       Among the materials (active layer material)
mentioned above, it should be noted that the mixed

25   crystal of GaInN(Sb)As can achieve the oscillation at

the wavelength longer than 1.1μm. Further, with the layer of the foregoing GaInN(Sb)As material, the band discontinuity at the conduction band is increased with respect to the GaAs layer used for a carriers confinement layer, and because of this, the overflow of the electron is successfully reduced. As a result, it is possible to obtain a stable oscillation even at high temperatures. In addition to these, the electrostatic capacitance of the n-type semiconductor distributed Bragg reflector is reduced in the surface-emission laser diode of the present invention. Because of this, it becomes possible to perform high speed modulation more easily as compared with a conventional device. According to the present invention, it becomes possible to provide a surface-emission laser diode suitable for optical telecommunication and optical transmission.

[Fifty-third Embodiment]

A fifty-third embodiment of the present invention is a surface-emission laser array formed of the surface-emission laser diode of any of the forty-fifth through fifty-second embodiments.

As the surface-emission laser array of the fifty-third embodiment is formed of the surface-

emission laser diode of any of the forty-fifth
through fifty-second embodiments, the electrostatic
capacitance of the device is small and high speed
modulation becomes possible.

5   Thus, in the surface-emission laser diode
constituting the surface-emission laser array of the
fifty-third embodiment, the electrostatic capacitance
caused by the n-type semiconductor distributed Bragg
reflector is reduced, and with this, high speed
10   modulation becomes possible. Thus, high speed
modulation becomes possible similarly in the surface-
emission laser array formed of such surface-emission
laser diodes. Further, by constructing a surface-
emission laser array, parallel optical transmission
15   is easily conducted, and it becomes possible to
conduct high speed and large capacity optical
transmission and optical telecommunication. Thus, in
the fifty-third embodiment, a surface-emission laser
array capable of performing high speed and large
20   capacity optical transmission and optical
telecommunication is provided.

[Fifty-fourth Embodiment]
          A fifty-fourth embodiment of the present
25   invention is a surface-emission laser module formed

of the surface-emission laser diodes of any of the forty-fifth through fifty-second embodiments or the surface-emission laser array of the fifty-third embodiment.

5   As the surface-emission laser module of the fifty-fourth embodiment is formed of the surface-emission laser diode of any of the forty-fifth through fifty-second embodiments or the surface-emission laser array of the fifty-third embodiment,

10   it becomes possible to conduct high speed and large capacity optical transmission and optical telecommunication.

Thus, a surface-emission laser diode or a surface-emission laser array in which the

15   electrostatic capacitance is reduced in the n-type semiconductor distributed Bragg reflector and capable of performing higher speed modulation, is used in the surface-emission laser module of the fifty-fourth embodiment, and because of this, high speed and large

20   capacity optical transmission and optical telecommunication become possible. More specifically, it should be noted that the $1.3 \mu m$ band coincides to the zero dispersion band of quartz in the case of the surface-emission laser module in which a $1.3 \mu m$ band

25   surface-emission laser diode that uses the GaInNAs

mixed crystal for the active layer is combined with a quartz single mode fiber as in the case of the example 7 to be described later. Because of this, such a construction is well suited to high speed

5   modulation. By using this surface-emission laser module, it is possible to conduct high speed and large capacity optical telecommunication and optical transmission. Thus, the fifty-fourth embodiment provides a surface-emission laser module capable of

10   conducting high speed and large capacity optical transmission and optical telecommunication.

[Fifty-fifth Embodiment]

            A fifty-fifth embodiment of the present

15   invention is an optical interconnection system formed of the surface-emission laser diode of any of the forty-fifth through fifty-second embodiments or a surface-emission laser array of the fifty-third embodiment or the surface-emission laser module of

20   the fifty-fourth embodiment.

            As the optical interconnection system of the fifty-fifth embodiment is formed of the surface-emission laser diode of any of the forty-fifth through fifty-second embodiments or the surface-

25   emission laser array of the fifty-third embodiment or

the surface-emission laser module of the fifty-fourth
embodiment, it becomes possible to conduct high speed
and large capacity optical transmission.

Thus, a surface-emission laser diode or a
5   surface-emission laser array or a surface-emission
laser module in which the electrostatic capacitance
is reduced in the n-type semiconductor distributed
Bragg reflector and capable of performing higher
speed modulation, is used in the optical
10   interconnection system of the fifty-fifth embodiment,
and because of this, high speed and large capacity
optical transmission and optical telecommunication
become possible. More specifically, it should be
noted that the 1.3μm band coincides to the zero
15   dispersion band of quartz in the case of the optical
interconnection system constructed by the surface-
emission laser module in which a 1.3μm band surface-
emission laser diode that uses the GaInNAs mixed
crystal for the active layer is combined with a
20   quartz single mode fiber as in the case of the
example 11 to be described later. Because of this,
such a construction is well suited to high speed
modulation. By using this surface-emission laser
module, it is possible to conduct high speed and
25   large capacity optical telecommunication and optical

transmission.

Also, it is possible to achieve stable oscillation up to high temperatures even in the case there is caused a change of environment temperature in which the

5　device is operated, in the case of the surface-emission laser diode that uses the GaInNAs mixed semiconductor crystal for the active, and because of this, it is possible to obtain highly reliable optical interconnection system. Thus, the **fifty-fifth**

10　embodiment provides a highly reliable optical interconnection system capable of performing high speed and large capacity optical communication.

[Fifty-Sixth Embodiment]

15　　　　A fifty-sixth embodiment of the present invention is an optical communication system formed of the surface-emission laser diode of any of the forty-fifth through fifty-second embodiments or a surface-emission laser array of the fifty-third

20　embodiment or the surface-emission laser module of the fifty-fourteenth embodiment.

　　　As the optical telecommunication system of the fifty-sixth embodiment is formed of the surface-emission laser diode of any of the forty-fifth

25　through fifty-second embodiments or the surface-

emission laser array of the fifty-third embodiment or the surface-emission laser module of the fifty-fourth embodiment, it becomes possible to conduct high speed and large capacity optical telecommunication.

5   Thus, a surface-emission laser diode or a surface-emission laser array or a surface-emission laser module in which the electrostatic capacitance is reduced in the n-type semiconductor distributed Bragg reflector and capable of performing higher

10 speed modulation, is used in the optical telecommunication system of the fifty sixth embodiment, and because of this, high speed and large capacity optical telecommunication become possible. More specifically, it should be noted that the $1.3 \mu m$

15 band coincides to the zero dispersion band of quartz in the case of the optical telecommunication system constructed by the surface-emission laser module in which a $1.3 \mu m$ band surface-emission laser diode that uses the GaInNAs mixed crystal for the active layer

20 is combined with a quartz single mode fiber as in the case of the example 11 to be described later. Because of this, such a construction is well suited to high speed modulation. By using this surface-emission laser module, it is possible to conduct high speed

25 and large capacity optical transmission. Also, it is

possible to achieve stable oscillation up to high
temperatures even in the case there is caused a
change of environment temperature in which the device
is operated, in the case of the surface-emission

5   laser diode that uses the GaInNAs mixed semiconductor
crystal for the active, and because of this, it is
possible to obtain highly reliable optical
telecommunication system. Thus, the fifty-sixth
embodiment provides a highly reliable optical

10   telecommunication system capable of performing high
speed and large capacity optical transmission.

Examples

Next, examples of the present invention

15   will be described.
<Example 5>

Figure 154 is a diagram explaining an
example of the n-type semiconductor distributed Bragg
reflector of the forty-first embodiment as Example 5.

20   The n-type semiconductor distributed Bragg reflector
of Figure 154 is a semiconductor distributed Bragg
reflector having a design reflection wavelength of
0.98μm and is constructed by periodically stacking
an n-AlAs layer and n-GaAs layer with an intervening

25   n-AlGaAs linear compositional graded layer

(intermediate layer) of 30nm thickness between the n-AlAs layer and the n-GaAs layer, wherein the Al content is changed linearly in the linear graded layer from a value to another value as shown in
5   Figure 155.

In the n-type semiconductor distributed Bragg reflector of Figure 154, the thickness of the n-AlAs layer is set to 51.6nm and the thickness of the n-GaAs layer is set to 40.9nm. It should be noted
10   that the thickness that satisfies the phase condition of multiple reflection in the semiconductor distributed Bragg reflector, in other words the thickness in which the phase change of the becomes π /2 in each of the foregoing semiconductor layers, is
15   82.9nm and 69.5nm respectively for the case of the light having the wavelength of 0.98$_{\mu}$m. However, the thickness of the n-AlAs layer and the n-GaAs layer are determined as above in consideration of the phase change taking place in the linear compositional
20   graded layer having the thickness 30nm.

The n-type semiconductor distributed Bragg reflector of Figure 154 can be formed by a crystal growth process conducted by an MOCVD process while using trimethyl aluminum (TMA), trimethyl gallium
25   (TMG) and arsine (AsH$_3$) gas for gas source material.

Thereby, it is possible to use hydrogen selenide (H_2Se) for the n-type dopant. In the MOVCD process, the composition of AlGaAs can be controlled easily by changing the supply rate of the source materials, and

5   thus, formation of the compositional graded layer can be achieved easily.

In the n-type semiconductor distributed Bragg reflector of Figure 154, not only the electrical resistance but also the electrostatic

10   capacitance at the heterointerface are reduced as compared with a conventional device, by providing the compositional graded layer (intermediate layer) to each heterointerface.

15   <Example 6>

Figure 171 is a diagram for explaining an example of the n-type semiconductor distributed Bragg reflector of the forty-third embodiment as Example 6. It should be noted that the n-type semiconductor

20   distributed Bragg reflector of Figure 171 is a semiconductor distributed Bragg reflector having a design reflection wavelength of $1.3\,\mu m$ and includes periodical stacking of an n-$Al_{0.9}Ga0.1As$ layer and an n-GaAs layer with an n-AlGaAs linear compositional

25   graded layer (intermediate layer) of 40nm thickness

interposed between the n-$Al_{0.9}Ga_{0.1}As$ layer and the n-GaAs layer, wherein the Al content of the linear compositional graded layer is changed linearly from one value to another value as shown in Figure 155.

5   Here, it should be noted that the thickness of each of the layers is determined by reducing the thickness corresponding to the phase change of light in the compositional graded layer similarly to Example 5, such that the phase condition of the

10   multiple reflection of the Bragg reflector is satisfied. Here, thickness of 40nm of the compositional graded layer is chosen to fall in the ranges of $20 < t \leqq (50\lambda - 15)$ [nm], which is determined ·with respect to the reflection wavelength λ $(=1.3\mu m)$

15   of the distributed Bragg reflector. With this, the electrostatic capacitance by the heterointerface was successfully reduced as compared with conventional device while maintaining high reflectivity. Thus, an n-type distributed Bragg reflector suitable for the

20   cavity reflector of a surface-emission laser element, and the like, was obtained.

<Example 7>

      Figure 156 is a diagram showing an example

25   of the surface-emission laser diode of the forty-

fifth and fifty-second embodiments as Example 7. It
should be noted that the surface-emission laser diode
of Figure 156 is a surface-emission laser diode of
the 1.3 μm band that uses GaInNAs for the active
layer and is formed by conducting the crystal growth
by an MOCVD process while using trimethyl aluminum
(TMA), trimethyl gallium (TMG), trimethyl indium
(TMI) and arsine gas (AsH$_3$) for the source material.
Thereby, it is possible to use dimethylhydrazine
(DMHy) for the nitrogen source material of the active
layer. Further, CBr$_4$ may be used for the p-type
dopant and H$_2$Se for the n-type dopant.

The surface-emission laser diode of Figure
156 is produced in the following manner. First,
crystal growth of an n-GaAs buffer layer is conducted
on the n-GaAs substrate, and thereafter, crystal
growth of the n-type semiconductor distributed Bragg
reflector is conducted by repeating the AlAs/GaAs
fundamental structure for 36 times. Thereby, the n-
AlGaAs linear compositional graded layer having the
thickness of 30nm is provided to each heterointerface
of the n-AlAs/GaAs semiconductor distributed Bragg
reflector as the intermediate layer (semiconductor
layer) as in the case of Example 5, such that that
the Al content changes linearly from the composition

of one of the semiconductor layers to the composition of the other semiconductor layer.

After forming the n-AlAs/GaAs semiconductor distributed Bragg reflector like this, a GaAs cavity spacer layer, a GaInNAs/GaAs multiple quantum well structure (active layer), a GaAs cavity spacer layer, and a p-type semiconductor distributed Bragg reflector are formed consecutively, wherein the p-type semiconductor distributed Bragg reflector includes 22 stacks of the $Al_{0.8}Ga_{0.2}As/GaAs$ pair. Here, it should be noted that there is provided an AlAs selective oxidation layer of 30nm thickness at the interface of the first pair in the p-type semiconductor distributed Bragg reflector. Further, in order to reduce the device resistance, there is provided a linear shape compositional graded layer (thickness of 30nm) at each interface of the p-type semiconductor distributed Bragg reflector such that the Al content changes linearly in the linear compositional graded layer from a first composition at a first side to another composition at the opposite side. Further, the GaAs layer forming the uppermost surface layer of the p-type semiconductor distributed Bragg reflector is used also for the contact layer by setting the doping density to 1×10^{19}

cm^{-3}.

Here, it should be noted that the thickness
of each layer constituting the p-type semiconductor
distributed Bragg reflector and the n-type

5 semiconductor distributed Bragg reflector here is
adjusted similarly to Example 5 such that the phase
condition of multiple reflection of the distributed
Bragg reflector is satisfied, including the
compositional graded layer (intermediate layer). Thus,

10 adjustment is made also to the thickness of the
$Al_{0.8}Ga_{0.2}As$ layer adjacent to the AlAs selective
oxidation layer. Further, it should be noted that the
phase change of the oscillation light in the region
including the active layer and also the two cavity

15 spacer layers of this surface-emission laser diode is
set equal to 2π. Thereby, there is formed 1λ cavity.
Thereby, it should be noted that the active layer is
disposed at the central position of the 1λ cavity of
central in correspondence to the anti-node of the

20 standing wave of light formed in the optical cavity.

Next, the layers from the surface of the p-
GaAs contact layer up to midway of the GaAs cavity
spacer layer contacting to the n semiconductor
distributed Bragg reflector are removed while leaving

25 the region constituting the device part in the form

of mesa by conducting known photolithographic process
and dry etching process. The mesa thus formed as the
device part has a square form of $30\mu m \times 30\mu m$.

Next, heating is conducted in the ambient
5   of bubbling pure water of 80℃ formed by using a
nitrogen gas, and a current confinement structure is
formed by conducting selective oxidation to as to
proceed laterally toward the device center from the
etched sidewall of the AlAs selective oxidation layer.
10   With this, a region serving for the current path is
formed with the size of $5\mu m \times 5\mu m$.

Next, the mesa part is buried by an
insulating resin such as polyimide, and evaporation
deposition and lift-off of an electrode material is
15   conducted to form a p-side electrode so as to form an
opening for optical exit at the device top surface.
Further, by forming the n-side electrode to the rear
surface of the substrate, it is possible to obtain
the surface-emission laser diode of Figure 156.

20   In the surface-emission laser diode of
Figure 156, there is provided the compositional
graded layer at the heterointerface of both of the p-
type semiconductor distributed Bragg reflector and
the n-type semiconductor distributed Bragg reflector.
25   It should be noted that the compositional graded

layer provided in the p-type semiconductor distributed Bragg reflector for reducing the device resistance as in the case of the known technology. On the other hand, by providing the n-type compositional

5 graded layer in the n-type semiconductor distributed Bragg reflector, the electrostatic capacitance of the device is reduced significantly as compared with a conventional device. In other words, the potential distribution such as spike, notch, and the like, at

10 the interface of the AlAs layer and the GaAs layer constituting the n-type semiconductor distributed Bragg reflector is smoothed in the surface-emission laser diode of Figure 156 by providing the n-type compositional graded layer to the n-type

15 semiconductor distributed Bragg reflector. With this, the accumulation or depletion of the carriers is suppressed and the electrostatic capacitance is reduced significantly. Thereby, a structure suitable for high speed modulation is obtained. In fact, the

20 surface-emission laser diode of Figure 156 is capable of performing high speed modulation of 10Gbps or more easily.

Also, it should be noted that the surface-emission laser diode of Figure 156 makes use of

25 GaInNAs for the active layer. With this, it became

possible to provide a surface-emission laser diode oscillating at the 1.3 μm by using the excellent semiconductor distributed Bragg reflector the having by the Al(Ga)As/GaAs structure on the GaAs substrate.

5 It should be noted that the GaInNAs mixed crystal provides a large conduction band discontinuity with regard to the barrier layer or cavity spacer layer of the GaAs, and the confinement effect of electrons to the active layer is improved. Because of this, a

10 stable oscillation is achieved up to high temperatures. Further, it should be noted that the 1.3 μm band coincides with the zero dispersion band of silica fiber, and it becomes possible to achieve high speed communication by using a quartz single

15 mode fiber. As noted above, high speed modulation is possible in the surface-emission laser diode of Figure 156. By combining with a quartz single mode fiber it becomes possible to conduct high speed communication easily.

20

<Example 8>

Figure 157 a diagram showing an example of the surface-emission laser diode of the forty-sixth and forty-eighth embodiment as Example 8. The

25 surface-emission laser diode of Figure 157 is a

surface-emission laser diode of the 0.98$_\mu$m band having an active layer of GaInAs/GaAs multiple quantum well and crystal growth is made on the n-GaAs substrate by an MOCVD process.

5   Thus, in the surface-emission laser diode of Figure 157, the n-type semiconductor distributed Bragg reflectors is formed by repeatedly conducting a crystal growth process of the $Al_{0.8}Ga_{0.2}As/GaAs$ for 36 times, and after this, the $Al_{0.15}Ga_{0.85}As$ cavity spacer

10   layer, the GaInAs/GaAs multiple quantum well structure, the $Al_{0.15}Ga_{0.85}As$ cavity spacer layer, and the p-type semiconductor distributed Bragg reflector are formed consecutively, wherein the p-type semiconductor distributed Bragg reflector includes

15   therein 22 stacks of the $Al_{0.8}Ga_{0.2}As/GaAs$ structure.

          In the surface-emission laser diode of Figure 157, it should be noted that the he linear compositional graded layer of the 30nm thickness for reducing the device resistance is provided only in

20   the p-type semiconductor distributed Bragg reflector. Further, it should be noted that an AlAs selective oxidation layer is provided similarly to Example 7 in the p-type semiconductor distributed Bragg reflector.

          Further, the thickness of the layer

25   constituting the semiconductor distributed Bragg

reflector is set so as to satisfy the phase condition
of multiple reflection of the distributed Bragg
reflector for the light of the oscillation wavelength
of 0.98μm in consideration of the thickness of the

5   compositional graded layer and the selective
oxidation layer.

Meanwhile, it should be noted that the path
of the electrons in the n-type semiconductor
distributed Bragg reflector is limited to the mesa

10 region in the surface-emission laser diode of Example
8 in view of the fact that the n-type semiconductor
distributed Bragg reflector is etched to the
substrate surface (in other words, the n-type
semiconductor distributed Bragg reflector is

15 processed and to form the mesa by way of conducting
etching (dry etching).

In a surface-emission laser diode, it
should be noted that the dry etching is primarily the
process conducted for preparation of the lateral

20 oxidation of the selective oxidation layer, and
because of this, it has been practiced in a
conventional surface-emission laser diode that the
etching removal process is conducted only up to
midway of the n-type semiconductor distributed Bragg

25 reflectors or midway of the cavity spacer layer or

only for a few pairs of the layers in the n-type
semiconductor distributed Bragg reflector. Thus, in
such a conventional surface-emission laser diode, the
n-type semiconductor distributed Bragg reflector does
5   not function as the confinement structure of
electrons, and the electron current is injected into
the active region from the n-side electrode was
provided to the entire rear surface of the substrate
through the n-type semiconductor distributed Bragg
10   reflector having an area larger than the mesa area.
Thereby, the electrostatic capacitance for the part
of the interface of the n-type semiconductor
distributed Bragg reflector acting as the path of the
electrons current becomes the capacitance of the
15   surface-emission laser diode.

Thus, by processing the n-type
semiconductor distributed Bragg reflector by etching
to have the area comparable to the area of the mesa
region as in the case of Example 8 (by processing in
20   the form of mesa), the electrostatic capacitance can
be successfully reduced. Thus, the surface-emission
laser diode of Example 8 has an electrostatic
capacitance smaller than a conventional device and is
well suited to high speed modulation. In fact, the
25   surface-emission laser diode of Example 8 was capable

of performing high speed modulation exceeding 10Gbps easily.

Also, it becomes possible to reduce the capacitance of the surface-emission laser diode more,

5 by using the n-type semiconductor distributed Bragg reflector of Figure 158 in the n-type semiconductor distributed Bragg reflector of the surface-emission laser diode of Figure 157. Thus, it should be noted that the n-type semiconductor distributed Bragg

10 reflector of Figure 158 is the one in which the n-AlGaAs linear compositional graded layer (intermediate layer) changing the Al content linearly from one side to the other side is provided to the heterointerface between the n-$Al_{0.8}Ga_{0.2}As$ layer and

15 the n-GaAs layer in the n-type semiconductor distributed Bragg reflector of Figure 154. By using the n-type semiconductor distributed Bragg reflector of Figure 158 for the n-type semiconductor distributed Bragg reflector of the surface-emission

20 laser diode of Figure 157, the electrostatic capacitance at the heterointerface is significantly reduced and the area of the region serving for the electron current path is confined, and contribution of such a region to the electrostatic capacitance is

25 reduced. In this way, it becomes possible to reduce

the device capacitance furthermore. Thus, by using the n-type semiconductor distributed Bragg reflector of Figure 158 to a n-type semiconductor distributed Bragg reflector in the surface-emission laser diode

5   of Figure 157, device structure extremely suitable for high speed modulation is obtained. In such a surface-emission laser diode, it was possible to conduct high speed modulation exceeding 10Gbps easily.

10 <Example 9>

Figure 159 is a diagram showing an example of the surface-emission laser diode of the forty-seventh and forty-eighth embodiment as Example 9. The surface-emission laser diode of Figure 159 is a

15 surface-emission laser diode of the 0.98μm band having an active layer of GaInAs/GaAs multiple quantum well and crystal growth is made on the n-GaAs substrate by an MOCVD process.

Thus, in the surface-emission laser diode

20 of Figure 159, the n-type semiconductor distributed Bragg reflectors is formed by repeatedly conducting a crystal growth process of the AlAs/GaAs for 36 times, and after this, the $Al_{0.15}Ga_{0.85}As$ cavity spacer layer, the GaInAs/GaAs multiple quantum well structure, the

25 $Al_{0.15}Ga_{0.85}As$ cavity spacer layer, and the p-type

semiconductor distributed Bragg reflector are formed
consecutively, wherein the p-type semiconductor
distributed Bragg reflector includes therein 22
stacks of the $Al_{0.8}Ga_{0.2}As/GaAs$ structure.

5   In the surface-emission laser diode of
Figure 159, it should be noted that the linear
compositional graded layer of the 30nm thickness for
reducing the device resistance is provided only in
the p-type semiconductor distributed Bragg reflector.

10   Further, it should be noted that an AlAs selective
oxidation layer is provided similarly to Example 8 in
the p-type semiconductor distributed Bragg reflector.

          Further, the thickness of the layer
constituting the semiconductor distributed Bragg

15   reflector is set so as to satisfy the phase condition
of multiple reflection of the distributed Bragg
reflector for the light of the oscillation wavelength
of 0.98μm in consideration of the thickness of the
compositional graded layer and the selective

20   oxidation layer.

          Meanwhile, the surface-emission laser diode
of Example 9 is formed by processing (dry etching)
the layers starting from the surface of the p-GaAs
contact layer up to the midway of the GaAs cavity

25   spacer layer adjacent to the n-semiconductor

distributed Bragg reflector to form a mesa structure similarly to Example 7, and by conducting hydrogen ion implantation into the n-type semiconductor distributed Bragg reflector while using the resist

5   pattern used at the time of the dry etching process as a mask, such that entire region of the n-type semiconductor distributed Bragg reflectors where the ion implantation has been made has a high resistance. In other words, the p-type semiconductor distributed

10 Bragg reflector has a high resistance except for the mesa region (cavity region). After such ion implantation, the oxidation confinement structure is formed by the selective oxidation process of the AlAs layer. Further, the insulation resin is provided and

15 the p-side electrode and the n-side electrode are formed similarly to Example 7.

As explained with Example 8, the n-type semiconductor distributed Bragg reflector does not form a confinement structure for the electrons in the

20 conventional surface-emission laser diode, and thus, the current path of the electrons spreads beyond the mesa diameter in the n-type semiconductor distributed Bragg reflector. Thus, the electrostatic capacitance of the heterointerface in this part of the n-type

25 semiconductor distributed Bragg reflector contributes

to the capacitance of the surface-emission laser
diode.

In the surface-emission laser diode of
Example 9, on the other hand, the electron current
5   path is confined by providing high resistance region
in the n-type semiconductor distributed Bragg
reflector by conducting hydrogen ion implantation
process, and because of this, it becomes possible to
eliminate unnecessary electrostatic capacitance. Thus,
10   the surface-emission laser diode of Example 9 has a
structure suitable for high speed modulation. Further,
because of formation of the confinement structure of
the electron current in the n-type semiconductor
distributed Bragg reflector by increasing the
15   resistance by hydrogen ion implantation. Because of
this, there is no need of increasing the mesa height
excessively, and the physical strength of the device
is improved. Further, filling of the insulation resin
can be conducted easily. Because of the fact that the
20   distance between the active region and the etched
surface are near in the surface-emission laser diode
of Example 9, there is no need of degrading the
efficiency of heat dissipation to the substrate, and
decrease of output power by heat is easily reduced.
25   In fact, it was possible to decrease the

electrostatic capacitance of the n-type semiconductor distributed Bragg reflector in the surface-emission laser diode of Example 9. Thus, it was possible to realize high speed modulation exceeding 10Gbps easily.

5   Further, it became possible to reduce the capacity of the surface-emission laser diode further, by using the n-type semiconductor distributed Bragg reflector of Figure 160 for the n-type semiconductor distributed Bragg reflector of the surface-emission

10 laser diode of Figure 159. Thus, the n-type semiconductor distributed Bragg reflector of Figure 160 is the one in which the n-AlGaAs linear compositional graded layer (intermediate layer) changing the Al content linearly from one side

15 thereof to the other said thereof is provided to the heterointerface between the n-AlAs layer and the n-GaAs layer, similarly to the n-type semiconductor distributed Bragg reflector of Figure 154. By using the n-type semiconductor distributed Bragg reflector

20 of Figure 160 as the n-type semiconductor distributed Bragg reflector of the surface-emission laser diode of Figure 159, the electrostatic capacitance caused by the heterointerface is can be reduced significantly. With this, the current path of the

25 electrons is confined and the area contributing to

electrostatic capacitance is reduced. In this way, it

becomes possible to reduce the device capacitance

furthermore, and a device structure well suited for

high speed modulation is obtained, by using the n-

5   type semiconductor distributed Bragg reflector of

Figure 160 for the n-type semiconductor distributed

Bragg reflector of the surface-emission laser diode

of Figure 159. With such a surface-emission laser

diode, it was possible to conduct high speed

10   modulation exceeding 10Gbps easily.

In the aforementioned examples (Example 5,

Example 7, Example 8, Example 9), the surface-

emission laser diode formed by conducting a crystal

growth process on an n-type semiconductor substrate

15   was shown. However, it is also possible to use a p-

type semiconductor substrate instead of the n-type

semiconductor substrate in the surface-emission laser

diode of the present invention.

For example Figure 161 is a diagram showing

20   an example of realizing the surface-emission laser

diode of Example 7 on a p-type semiconductor

substrate. It should be noted that the surface-

emission laser diode of Figure 161 is formed by

conducting a crystal growth process on a p-GaAs

25   substrate by an MOCVD process. More specifically, the

surface-emission laser diode of Figure 161 is formed
by conducting a crystal growth to form a p-GaAs
buffer layer on the p-GaAs substrate, followed by
repeatedly growing the $Al_{0.8}Ga_{0.2}As$/GaAs structure for

5   36 stacks to form the p-type semiconductor
distributed Bragg reflector. Thereafter, the GaAs
cavity spacer layer, the GaInNAs/GaAs multiple
quantum well active layer, the GaAs spacer layer, and
the n-type semiconductor are formed consecutively,

10 wherein the n-type semiconductor is formed by
stacking the $Al_{0.8}Ga_{0.2}As$/GaAs fundamental structure
for 26 times.

Here, it should be noted that a linear
compositional graded layer (30nm thickness) is

15 provided to each of the heterointerfaces of the p-
type semiconductor distributed Bragg reflector for
reducing the electrical resistance in such a manner
to satisfy the phase condition of multiple reflection
of the semiconductor distributed Bragg reflector.

20 Further, the AlAs selective oxidation layer is
provided to the $Al_{0.8}Ga_{0.2}As$/ GaAs heterointerface
nearest to the active layer in conformity with the
phase condition. Further, the n-type semiconductor
distributed Bragg reflector of the present invention

25 is used for the n-type semiconductor distributed

Bragg reflector. Thus, a linear compositional graded layer (30nm thickness) is provided to each heterointerface of the n-type semiconductor distributed Bragg reflector as the intermediate layer

5 (semiconductor layer) for reducing the electrostatic capacitance.

In the surface-emission laser diode of Figure 161, a dry etching process, selective oxidation process, filling with the insulating resin,

10 formation of the electrode, and the like, are conducted after the crystal growth process, similarly to Example 7. Thereby, it should be noted that, in order to enable oxidation of the AlAs selective oxidation layer in the p-type semiconductor

15 distributed Bragg reflector, a dry etching process is conducted to the midway of the p-type semiconductor distributed Bragg reflector.

In the surface-emission laser diode of Figure 161, it should be noted that high speed

20 modulation exceeding 10Gbps was achieved easily as a result of the decrease of the electrostatic capacitance of the n-type semiconductor distributed Bragg reflector similarly to Example 7.

Further, Figure 162 is a diagram showing

25 another example of the surface-emission laser diode.

The surface-emission laser diode of Figure 162 is produced similarly to the surface-emission laser diode of Figure 161 and there is provided a compositional graded layer in the p-type

5   semiconductor distributed Bragg reflector for reducing the electrical resistance. Further, such a compositional graded layer (intermediate layer) is provided also in the n-type semiconductor distributed Bragg reflector for reducing the electrostatic

10   capacitance. In the surface-emission laser diode of Figure 162, it should be noted that hydrogen ion implantation is carried out similarly to Example 9 after the dry etching process for forming the mesa region. With this, the resistance of the p-type

15   semiconductor distributed Bragg reflector is increased except for the mesa region (cavity region). Thus, current path of the holes is reduced to be generally equal to the mesa diameter, and the electrostatic capacitance of the p-type semiconductor

20   distributed Bragg reflector is reduced. Thereby, the structure of Figure 162 is suited for further high speed modulation as compared with the device of Figure 161.

In the examples (Example 5, Example 7,

25   Example 8, Example 9) mentioned above, the crystal

growth for producing the surface-emission laser diode
was conducted by an MOCVD process. However, it is
also possible to conduct the crystal growth by using
a growth method other than the MOCVD process. Further,

5   in the above examples, a linear compositional graded
layer was used as the intermediate layer
(semiconductor layer having the refractive index (the
bandgap) intermediate of the two kinds of the
semiconductor layers) provided between two kinds of

10   semiconductor layers having respective, mutually
different refractive indices and constituting the
semiconductor distributed Bragg reflector, while it
is also possible to use a layer in which the
composition is changing to non-linearly for the

15   intermediate layer. Also, it is possible to use a
layer formed of single or plural layers having
different refractive indices.

<Example 10>

20   Figure 163 is a diagram showing an example
of the surface-emission laser array of the fifty-
third embodiment as Example 10. The surface-emission
laser array of Figure 163 is a monolithic laser array
in which 3×3 surface-emission laser diodes of the

25   present inventions mentioned above are integrated in

the form of two-dimensional array. In the surface-
emission laser array of Figure 163, separate p-side
electrode wirings are provided for driving the
individual surface-emission laser diode independently.

5   The surface-emission laser array of Figure 163 is
produced with the procedure and method similar to
those of Example 5, Example 7 or Example 9.

In the surface-emission laser array of
Figure 163, the electrostatic capacitance caused by
.10   the n-type semiconductor distributed Bragg reflector
is reduced in each of the surface-emission laser
diodes constituting the surface-emission laser array.
Accordingly, this surface-emission laser array has a
structure well suited to high speed modulation, and
15   in fact, high speed modulation was possible.

<Example 11>

Figure 164 is a diagram showing an example
of the surface-emission laser module of the fifty-
20   fourth embodiment as Example 11. It can be seen that
the surface-emission laser module of Figure 164 is
formed of a one-dimensional monolithic surface-
emission laser array, a micro lens array and a fiber
array (quartz single mode fiber) mounted on silicon
25   substrate.

Here, it should be noted that the surface-
emission laser array of the fifty-third embodiment is
provided so as to oppose the fibers, and the surface-
emission laser array is coupled with the quartz

5   single mode fibers mounted in the V-grooves formed on
the silicon substrate by way of a micro lens array.
The oscillation wavelength of this surface-emission
laser array is in the 1.3 μm band. Thus, by using the
quartz single mode fiber, it is possible to conduct

10   high speed parallel optical transmission.

Further, by using the surface-emission
laser array of the fifty-third embodiment as the
optical source of the surface-emission laser module
of Figure 164, high speed modulation becomes possible,

15   and a surface-emission laser module capable of
performing high speed transmission can be obtained.

<Example 12>

Figure 165 is a diagram showing the

20   parallel optical interconnection system as an example
of the optical interconnection system of the fifty-
fourth embodiment. In the inter connection system of
Figure 165, a device 1 and a device 2 are connected
by using an optical fiber array (quartz single mode

25   fiber array). Here, it should be noted that the

device 1 at the transmission side includes the
surface-emission laser module formed by the surface-
emission laser array of the fifty-fourth embodiment
and a driver circuit thereof. Further, the device 2

5   at the reception side includes a photodiode array
module and a signal detection circuit.

In the optical interconnection system of
Figure 165, high speed parallel optical transmission
becomes possible by using the surface-emission laser

10 module of the fifty-fifth embodiment. Further, a
surface-emission laser array having the active layer
of GaInNAs is used for the surface-emission laser
module. With this, it is possible to obtain stable
oscillation even if there is caused change of

15 environmental temperature. As a result, an inter
connection system of very high reliability can be
constructed.

In an abovementioned example, explanation
was made fro the example of parallel optical

20 interconnection system. However, in addition to this,
it is possible to construct a serial transmission
system that uses a simple device. Further, the
present invention is not limited to the
interconnection between devices but the present

25 invention is applicable also to the inter connection

between boards, between chips, or inside a chip.

<Example 13>

Figure 166 is a diagram showing an optical

5   LAN system as an example of the optical

telecommunication system of the fifty-sixth

embodiment. It should be noted that the optical LAN

system of Figure 166 is constructed by the surface-

emission laser diode or the surface-emission laser

10 array or the surface-emission laser module of the

present invention mentioned above.

Thus, in the optical LAN system of Figure

166, the surface-emission laser diode or the surface-

emission laser array or the surface-emission laser

15 module of the present invention mentioned above is

used for the optical source of optical transmission

between the core switch and the server, and/or for

the optical source of optical transmission between

the core switch and each switch, and /or for the

20 optical source of optical transmission between the

switch and each terminal. Further, a quartz single

mode fiber or multimode fiber is used for

interconnection between the devices. A Giga-bit

Ethernet of 1000BASE-LX, and the like, can be an

25 example of the physical layer of such an optical LAN.

In the optical LAN system of Figure 167, high speed communication became possible as a result of use of the surface-emission laser diode or the surface-emission laser array or the surface-emission laser module of the present invention that mentioned above for the optical source of optical transmission. Further, in the surface-emission laser of the present invention that uses GaInNAs for the active layer, stabile oscillation was obtained even if there is caused change of the operational environmental temperature, drive condition, and the like, and it becomes possible to construct a highly reliable optical telecommunication system.

The present invention is not limited to the embodiments described heretofore, but various variations and modifications may be made without departing from the scope of the invention.

The present application is based on Japanese priority applications No.2001-050145 filed on February 26, 2001, No.2001-050171 filed on February 26, 2001, No.2001-050083 filed on February 26, 2001, No.2001-051253 filed on February 26, 2001, No.2001-051256 filed on February 26, 2001, No.2001-051266 filed on February 26, 2001, No.2001-053213

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2002, No.2002-033590 filed on February 12, 2002,

No.2002-50548 filed on February 26, 2002, No.2003-

118115 filed on April 23, 2003, the entire contents

10   of which are hereby incorporated by reference.